THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

RECEIVED
FEB 29 1956
LIBRARY

DECEMBER, 1955

	Page
General	
A.S.M. Metals Handbook: Revised Sections	205
Influence of Surface Films on Friction and Wear	205
Identification of Metals prior to Welding	206
Brazing Materials and Technique: A.W.S. Handbook	206
Mechanism of Sintering in Non-Ferrous Metals	206
Nickel	
Laterite Nickel Ores	207
Stored Energy and Lattice Defects in Cold-Worked Nickel	207
Gyromagnetic Ratio of Nickel	207
Nickel Catalysts: Review of Literature	207
Hydrogen in Raney Nickel Catalysts	207
Specificity of Nickel Catalyst: Sulphur Poisoning	208
Oxide-Impregnated Nickel-Matrix Cathode	208
Excess Barium in Oxide-coated Cathodes	208
Argon-Arc Welding of Nickel	209
Thioacetamide Separation of Nickel and Cobalt	209
Determination of Lead and Copper in Nickel	210
,, ,, Nickel in Titanium Alloys	210
,, ,, Traces of Nickel in Petroleum	210
Magnetic and Electrical Properties of Nickel Oxide	210
Heat of Formation of Nickel Carbonyl	210
Adsorption of Chlorine Trifluoride on Porous Nickel Fluoride	211
Properties of Nickel Difluoride	211
Nickel Compounds in Detection of Formaldehyde	211
Electrodeposition and Other Coating Methods	
Evaluation of Surface Cleanliness	211
Anodic Etching prior to Plating	212
Bright Nickel Plating: Solutions, Technique, etc.	212
Protective Coatings, Metallic and Non-Metallic	213
Electroless Nickel Plating of Ceramics	213
Tin-Nickel Alloy Plating	214
Electrophoretic Deposition of Nickel and Other Metals	214
Non-Ferrous Alloys	
Ternary Nickel-Chromium-Carbon Alloys	214
Grain-boundary Diffusion of Nickel into Copper	214
Self-Diffusion in Nickel-Gold Alloys	215
Young's Modulus of Nickel-Cobalt Alloys	215
Ferromagnetic Hall Coefficient of Nickel Alloys	215
Influence of Nickel on Corrosion-Resistance of Titanium	215
Analysis of Light Metals and Alloys	215
Nickel-Iron Alloys	
Nickel-containing Alloys in Bimetal Combinations	216
Nickel-Iron-base Alloy Strip: Specifications	216
Vacuum Evaporation of Thin Films of Nickel-Iron Alloys	216
Nickel 'Ferrites'	216
Cast Iron	
Austenitic S.G. Iron	217
Alloy Cast Iron for Elevated-Temperature Use	217
Overlaying of Ferrous Materials with High-Nickel Alloys	219
S.G. Iron for Dies and Tools	219
S.G. Iron in the Petroleum Industry	219
Constructional Steels	
Rare-Earth Additions to Nickel-containing Steels	220
Strength of Materials: Textbook	220
Thermal-Fatigue Cracking in Steels	220
Low-Alloy Steel for Pressure Vessels	220
A.I.S.I. Specifications for Low-Alloy Steels	221
Heat- and Corrosion-Resisting Materials	
High-Temperature Alloys: Compositions and Properties	221
Nickel-base Alloys for Use at High Temperatures	221
Nickel-Chromium-Cobalt-base Alloy: Jetalloy 1570	222
Gas Turbines and Jet Propulsion: Textbook	222
Structural Changes in Low-Alloy Steels during Creep	222
S.A.E. Aircraft Research Seminar: Design, Materials, etc.	223
Steels and Plated Coatings for Use up to 1000°F. (540°C.)	225
Anodic Etching of Precipitation-Hardening Nickel-Chromium Alloys	227
Machining of Aircraft Gas-Turbine Components	227
Carbon-Dioxide Coolant in Machining of Nimonic Alloys	227
Metallography of Delta Ferrite in Alloy Steels	227
Diffusion of Iron in Austenitic Nickel-Chromium Steel	228
Tension-Impact Properties of Stainless Steels	228
High-Temperature Properties of H.N.M. Stainless Steel	230
Resistance of Metallic Materials to Phosphoric Acid	230
Corrosion in High-Temperature Water	230
Equipment used in Production of Wood Vinegar	231
Resistance of Metallic Materials to Smoke from Locomotives	231
Inert-Gas-Shielded Arc Welding of Metals and Alloys	232
Welding of Austenitic Niobium-stabilized Stainless Steel	233
Moisture in Coatings of Austenitic Welding Electrodes	233
Brazing of Titanium to Stainless Steel	234
A.W.S.-A.S.T.M. Specifications for Austenitic Welding Electrodes	234
Nickel-base Brazing Alloys	234
High-Alloy Casting Materials: Specifications	235
Stainless-Steel Tubing: Specifications	235
High-Expansion Nickel-Manganese Steel	235
A.S.M. Metals Handbook: Stainless-Steel Section	235
Materials used in Chemical Engineering: Review	236
Precipitation-Hardening Austenitic Steel Castings	236
Valves for Handling Corrosive Fluids	236
Cavitation Testing of Metals and Alloys	237
Determination of Galvanic-Couple Corrosion in Atmospheric Conditions	237
Index to Volume 28	238

VOLUME 28 NUMBER 12

THE MOND NICKEL COMPANY LTD · THAMES HOUSE, MILLBANK, LONDON, S.W.1
Telephone:- Victoria 3888

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

A.S.M. Metals Handbook: Revised Sections

The AMERICAN SOCIETY FOR METALS has published (in the form of an issue of *Metal Progress* dated Aug. 15, 1955), a second group of Committee Reports supplementing the 1948 A.S.M. Metals Handbook. (The first supplement was sent out in *Metal Progress* of July 15, 1954.)

The scope of the Technical Committee Reports now issued is shown below:—

Metals and Applications

Selection of Sheet Steel for Formability
„ of Material for Press Forming Dies
„ and Application of Stainless Steel in the Chemical-Process Industries (see abstract on p. 235).
Selection of Aluminium Alloy Castings

Design and Application

Design of Closed-Die Forgings
Helical Steel Springs
Surface Finish of Metals
Residual Stresses
Selection of Electroplated Coatings (including extensive reference to the properties and uses of nickel and nickel/chromium coatings)

Processing and Fabrication

Induction Hardening and Tempering
Flame Hardening
Gas Carburizing
Control of Surface Carbon Content in Heat-Treatment of Steel
Forging and Heat-Treating of Tool Steel
Selection of Electrodes for Manual Arc Welding of Low-Carbon Steel
Metal-Cleaning Costs

Testing and Inspection

Creep and Creep-Rupture Tests
Radiography of Metals
Macro-Etching of Iron and Steel.

Strength of Materials: Textbook

See abstract on p. 220.

Influence of Solid Surface Films on Friction- and Wear-Resistance

E. E. BISSON, R. L. JOHNSON, M. A. SWIKERT and D. GODFREY: 'Friction, Wear and Surface Damage of Metals as Affected by Solid Surface Films.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 3444, May, 1955; 60 pp.

This comprehensive report is based on research data obtained in a series of investigations on lubrication, friction and wear, conducted under the auspices of the National Advisory Committee for Aeronautics over the period 1946–1954. The experiments reported were designed to demonstrate the relation of surface films formed naturally, pre-formed, or formed by other methods, on friction, wear and surface damage of sliding metals.

In an opening discussion on the theory of friction, it is shown that the basic requirement for reduction of such effects is the presence of a 'contaminant'* of low shear strength. This contaminant performs two functions, either or both of which may be influential: (1) reducing the amount of welding occurring at the rough areas on the surface, (2) decreasing the shear force operating. In order to perform the second function, the contaminant must be a material of lower shear strength than the softer of the two materials which are sliding against one another.

In the experimental work recorded, five different types of test apparatus were used, providing for three different kinds of kinetic friction, for static friction, and for reciprocating sliding. In most cases both specimens were of steel, but some studies were made on nickel, on selected alloys (including Nimonic 80 and Inconel), and on copper alloys. Solid films, the influence of which was investigated, included various oxides, sulphides and chlorides of iron, as well as materials such as molybdenum disulphide, graphite, lacquers, and varnishes.

The results of the tests indicate that the ability of materials to form surface films which prevent welding is an important factor in behaviour of dry and boundary-lubricated surfaces. Films of graphitic carbon on cast irons, of NiO on nickel alloys, and of FeO and Fe_3O_4 on ferrous materials, were found to be beneficial. Abrasive films such as Fe_2O_3 were detrimental. The observations made suggest that the importance of oxide films in relation to friction and wear has not previously been fully realized.

Chemical-reaction films of FeS and $FeCl_2$ were effective in preventing surface welding: due to its lower shear strength, the $FeCl_2$ was more effective than FeS in reducing friction.

It is concluded that solid lubricants such as molybdenum disulphide and graphite warrant careful consideration for use under severe conditions, e.g., at high temperatures. Both substances can be bonded to many surfaces by use of a resin-forming liquid. In the presence of oxygen MoS_2 oxidizes to MoO_3; the reaction is slow at 750°F. (400°C.), but becomes more rapid above 1050°F. (565°C.).

Excess Barium in Oxide-Coated Cathodes: Effects on Performance and Methods of Measurement

See abstract on p. 208.

* A contaminant is defined as any material other than those comprising the sliding surfaces.

Analysis of Light Metals and Alloys

See abstract on p. 215.

Qualitative Identification of Metals Prior to Welding

A. L. PHILLIPS: 'Shop Methods for Identifying Some Metals Prior to Welding.'
Welding Jnl., 1955, vol. 34, Sept., pp. 877–81.

Practical 'work-shop' notes on tests which may be applied to give broad identification. Methods described include—

(1) *hardness tests*, by file, or scleroscope;
(2) *chip tests*, in which the material is roughly identified by the nature of the chip formed;
(3) *spark tests* by grinding (a chart illustrating the form of sparks typical of various materials is shown);
(4) *identification by the type of service* which the material is known to have performed.

Some of the principal physical characteristics of steels and non-ferrous metals and alloys are broadly reviewed, and in a few cases chemical drop tests are described.

The article is a condensed and relatively elementary treatment of the subject.

Inert-Gas-Shielded Arc Welding of Metals and Alloys

See abstract on p. 232.

Argon-Arc Welding of Nickel and Other Metals

See abstract on p. 209.

Brazing Materials and Technique: A.W.S. Handbook

AMER. WELDING SOC.: 'Brazing Manual.'
Published by *Reinhold Publishing Corpn., New York; Chapman and Hall, Ltd., London*, 1955.
193 pp. Price $4.75.

This manual is confined strictly to discussion of brazing processes (and materials for them), within the A.W.S. definition of brazing as 'a group of welding processes wherein coalescence is produced by heating to a suitable temperature above 800°F. (425°C.) and by using a non-ferrous filler metal having a melting point below that of the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.'

The first eleven chapters cover the essential features of various brazing processes and the equipment used; the composition and properties of base metals which can be brazed, with discussion of some metallurgical features influencing the quality of brazed joints; brazing filler materials; fluxes and atmospheres; joint design; pre-cleaning and surface preparation; assembly; general technique of brazing; post-braze operations, and inspection.

The second part of the manual contains chapters on the brazing of individual materials, e.g., aluminium and aluminium alloys, magnesium, copper and copper-base alloys, low-carbon and alloy steels, stainless steels, high-carbon and high-speed tool steels, cast irons, heat-resisting alloys, nickel and high-nickel alloys, precious-metal contacts, and other materials. A final chapter makes reference to hazards arising in connexion with brazing operations, and an appendix embodies a tabular summary of the composition and properties of materials which can be brazed. A.W.S. Standards and books on welding, soldering and brazing are listed.

Mechanism of Sintering: Study with Copper and Nickel Wires

G. F. HÜTTIG, K. TORKAR and H. H. WEITZER: 'Investigation of the Sintering Mechanism of the System Copper–Nickel by means of Ferromagnetic Suspensions.' *Powder Metallurgy Bull.*, 1955, vol. 7, Aug., pp. 48–52.

The mechanism of sintering has been studied by some investigators by sintering of bundles of wires of different metals and microscopical observation of the change in cross-section of the wires. In other cases thin nickel wires have been wound round a copper cylinder and a study has been made of the migration of metal into the notch formed between wire and cylinder.

During studies of Weiss domains, by observation of the Bitter powder pattern, the present authors concluded that such a method could be applied by study of diffusion zones. This technique makes use of a very fine suspension of a ferromagnetic powder (magnetite), which, when applied to the polished section of a ferromagnetic specimen in the presence of a magnetic field, collects preferentially at the regions of the largest field gradients. The striations or patterns so produced are, on a microscopic scale, related to the size and orientation of the Weiss domains. On a macroscopic scale, use of the technique reveals the borderline between ferromagnetic and non-ferromagnetic regions. Since the applicability of the method is limited to systems in which one of the components is ferromagnetic, copper and nickel were chosen as the metals for the experiments. A further advantage was that previous studies of diffusion, by magnetic analysis, had established that copper-nickel solid solutions containing more than 32 per cent. of copper are no longer ferromagnetic. When copper diffuses into nickel, the copper content of the solid solutions formed in the diffusion zones changes continuously. In a magnetic field, the magnetite suspension accumulates at the points where a copper concentration of 32 per cent. has been reached, permitting observation of the location of this boundary after various sintering times.

The specimens studied consisted of a bundle of copper wires with a few nickel wires distributed among them, so that each nickel wire was surrounded by copper. All the wires were 0·3 mm. The bundle was sintered in a stream of hydrogen at 860°C., and at various stages the bundle was removed from the furnace, sections were cut off, and metallographic specimens were prepared. The report includes photomicrographs of sections to which the magnetic

suspension had been applied in a magnetic field, and comments are made on the significance of the changes observed.

The results confirm the course of sintering proposed in 1935 by Hüttig:—(1) adhesion, (2) surface diffusion, at which stage the lower-melting component surrounds the other one; (3) volume diffusion, when the lower-melting component penetrates from the surface into the interior and at first forms a disordered lattice of the final alloy, and (4) homogenization by volume diffusion.

Carbon-Dioxide Coolant in Machining of Metals and Alloys

See abstract on p. 227.

Gas Turbines and Jet Propulsion

See abstract on p. 222.

NICKEL

Genesis of Laterite Nickel Ores

D. R. DE VLETTER: 'How Cuban Nickel Ore was Formed: A Lesson in Laterite Genesis.' *Engineering and Mining Jnl.*, 1955, vol. 156, Oct., pp. 84–87, 178.

The author gives notes on the geology and geochemical reactions involved in the formation of lateritic nickel ores, with special reference to conditions obtaining in the Cuban nickel deposits, where typical laterites are found. These deposits form the world's largest reserves, having some 24 million tons of nickel content. Data are given on mineralogy and genesis, weathering of serpentine, and distribution of nickel, cobalt, iron and other minerals in the various strata of the ores.

Stored Energy and Lattice Defects in Cold-Worked Nickel

W. BOAS: 'Stored Energy and Lattice Defects in Cold-Worked Metals.' Reprint from Report of 1954 Bristol Conference on *Defects in Crystalline Solids*, pp. 212–21.

The author reports measurement of the changes in internal energy, electrical resistivity, density and hardness occurring during the annealing of copper and nickel which have been deformed at room temperature. The results obtained indicate that almost all the energy stored in copper is due to dislocations, but that vacancies make a significant contribution to that stored in nickel.

Gyromagnetic Ratio of Nickel

C. G. SCOTT: 'Gyromagnetic Ratio of Nickel at Low Magnetic Intensities.' *Physical Rev.*, 1955, vol. 99, Sept. 15, pp. 1824–5.

It has recently been shown that the measured value for the gyromagnetic ratio of iron is field-dependent in the low-intensity region, and that the extrapolated zero intensity value of this ratio agrees with that which is theoretically to be expected from a consideration of recent ferromagnetic resonance experiments. Measurements on a sample of pure nickel have yielded similar results.

Mechanism of Sintering: Study with Copper and Nickel Wires

See abstract on p. 206.

Influence of Solid Surface Films on Friction- and Wear-Resistance

See abstract on p. 205.

Nickel Catalysts: Review of Recent Literature

P. B. BOYD: 'Hydrogenation and Hydrogenolysis.' *Industrial and Engineering Chemistry*, 1955, vol. 47, Sept., Pt. II, pp. 1883–91.

This article, which forms part of the I. and E.C. Eighth Annual Review of Unit Processes in Chemical Engineering, is a survey of the literature which became available in 1954 on the following subjects: carbon oxides; oxo synthesis; oil and fat hydrogenation; hydrogenation of acetylenes, olefins and other hydrocarbons; ammonia synthesis; hydrogenation of petroleum, coal and related materials; hydrogenation of organic compounds, and fundamental studies of hydrogenation catalysts. The review is arranged in tabular form, classified, in each of the groups shown above, according to catalysts used, processes considered, fundamental studies of catalysts and their behaviour. The survey, supported by an extensive classified *bibliography*, contains many references to nickel-containing catalysts of various types.

Hydrogen in Raney Nickel Catalysts

H. A. SMITH, A. J. CHADWELL and S. S. KIRSLIS: 'The Rôle of Hydrogen in Raney Nickel Catalyst.' *Jnl. Physical Chemistry*, 1955, vol. 59, Sept., pp. 820–2.

In the reaction of nickel-aluminium alloy to form Raney nickel catalyst a considerable amount of hydrogen is formed, and the amount and character of the hydrogen present in the finished catalyst has been the subject of some controversy, the main items of which are recapitulated as an introduction to this paper. The work now described was designed to evaluate more closely the hydrogen content of typical Raney nickel catalysts and to assess the influence of hydrogen content on the activity of the catalyst in hydrogenation of benzene, and on its ability to adsorb palmitic acid.

Amounts of hydrogen obtained from various samples of catalyst, all prepared in the same manner, showed considerable variation, i.e., between one half and one atom of hydrogen per atom of nickel. Activity dropped in linear relation to removal of hydrogen. Surface area also decreased with removal of hydrogen: the relation was linear until about 70 per cent. of the hydrogen had been removed and after that stage

the decrease in surface area was more rapid. It was found that if the hydrogen was rapidly removed heat was evolved, and an explosion of the catalyst occurred.

The phenomena observed are most satisfactorily explained by assuming that the hydrogen is present in the form of atoms attached to the nickel in a metastable state. If desorption of the hydrogen is rapid the highly exothermic re-combination of the hydrogen atoms becomes explosive.

Specificity of Nickel Catalyst: Effect of Sulphur Poisoning

H. LINES, M. SHAMAIENGAR and W. S. POSTL: 'Specificity of Nickel Catalysts. Effect of Organic Additives upon the Reductive Dehydroxymethylation and Dehydroxylation of Primary Alcohols.' *Jnl. Amer. Chemical Soc.*, 1955, vol. 77, Oct. 5, pp. 5099–102.

It had been previously reported that nickel-kieselguhr, Raney nickel, or precipitated nickel catalysed the reductive dehydroxymethylation of saturated primary alcohols. The reaction proceeded according to the equation: $RCH_2OH + 2H_2 \rightarrow RH + CH_4 + H_2O$. It was found subsequently that another reaction, mainly reductive dehydroxylation, occurred when small amounts of sulphur-containing compounds, such as thiophene, dimethyl disulphide, dibenzyl sulphoxide, etc., were added to the alcohol. The presence of chloroform also caused reductive dehydroxylation. In explanation it is suggested that the catalysts possess inherent acid properties and that the sulphur compounds, through their ability to poison the active contact sites of a nickel catalyst, accentuate its acid properties. In conformity with the above views, it was found that in the presence of pyridine and thiophene both reductive dehydroxymethylation and dehydroxylation reactions are inhibited.

Oxide-Impregnated Nickel-Matrix Cathode

W. BALAS, J. DEMPSEY and E. F. REXER: 'Oxide-Impregnated Nickel-Matrix Cathode.' *Jnl. Applied Physics*, 1955, vol. 26, Sept., pp. 1163–5.

This paper appears to be the full form of that referred to, from an abstract source, in *Nickel Bulletin*, 1954, vol. 27, Nos. 7–8, p. 126.

During the past few years reports have been published on modifications which could be made in the structure of cathodes with a view to minimizing some of the limitations inherent in the common oxide-coated cathode. One of the first of the modified types proposed was a design in which a nickel mesh was employed for holding sprayed (BaSr)O. More recently there have been descriptions of a dispenser type, known as the *L*-cathode, which is reported to be capable of higher current densities, long life and resistance to poisoning (see *Electronics*, 1951, vol. 24, p. 104; *Jnl. Applied Physics*, 1953, vol. 24, p. 233). Other proposals have been for a moulded cathode (*Jnl. Applied Physics*, 1953, vol. 24, p. 1335) and for capillary cathodes (*ibid.*, 597).

The cathode described in this paper employs a nickel matrix impregnated with (BaSr)O. Experiments already made indicate that it has a low work function and can therefore be operated at a low temperature. It is easy to fabricate, exhibits good arcing properties, and although no exhaustive trials have yet been made with regard to susceptibility to poisoning, evaporation characteristics, and life, indications from preliminary tests are that the cathode will be satisfactory in these respects.

Nickel powder, 37–44μ, is pressed and formed in dies, or may be directly moulded to shape in a cathode retainer cup. The compacted matrix is then sintered in a hydrogen atmosphere, for about 10 minutes at 1000°C. Matrices so made are mechanically strong and well suited to withstand normal rough usage. By adjustment of production conditions, matrix porosity can be controlled within wide limits: the results reported in this paper were obtained with cathodes having a porosity of about 50 per cent.

After sintering, the matrix is impregnated with a water-soluble (BaSr) salt, and (BaSr) carbonate is then precipitated within the interstices by a second impregnation with a water-soluble carbonate. For the first impregnation (BaSr) acetate has been found to be a suitable medium, and the solution should be of high concentration. $(NH_4)_2CO_3$ has been used as the precipitating agent, since it has the advantage that its by-products in the precipitating reaction are water-soluble and decompose at low temperatures. The equations of the reactions involved are given in the original. The $(BaSr)CO_3$ is found primarily in the interstices, and there is a minimum of surface deposit. It is adhesively bonded to the matrix and is held in the pores by mechanical means, on the surface and within the body: there is thus very little possibility of the cathode material flaking off, and the cathode surface is virtually metallic in appearance. The cathodes can be activated by procedures closely similar to those used for normal oxide-coated cathodes. Pulse-emission tests, recorded in the paper in comparison with tests on other cathodes, show that the nickel-matrix impregnated type has properties intermediate between those of the oxide-coated and the *L*-cathodes, and of the same order as those of the moulded cathode.

Excess Barium in Oxide-Coated Cathodes: Effects on Performance and Methods of Measurement

L. A. WOOTEN, G. E. MOORE and W. G. GULDNER: 'Measurement of Excess Barium in Practical Oxide-Coated Cathodes.' *Jnl. Applied Physics*, 1955, vol. 26, Aug., pp. 937–42.

The limitations of conventional methods of measuring excess barium in cathodes are critically considered, and a modified procedure is described. By it, measurements were made on cathodes and filaments, of various forms and made from various materials (nickel of several grades, platinum, and Konal, a nickel-cobalt-iron-titanium alloy). The experiments showed that, due to side reactions, accurate measurement of barium in a cathode coating is more difficult

than had been previously realized. Significant interference may be caused by impurities in the nickel or platinum support metal.

See also—

G. E. MOORE, L. A. WOOTEN and J. MORRISON: 'Excess Barium Content of Practical Oxide-coated Cathodes and Thermionic Emission.' *ibid.*, pp. 943–8.

In the work described in this paper use was made of the methods described in the earlier one: see preceding abstract. The purpose of the investigation was (1) to measure, in various cathode structures, the excess barium content of the coating in each of several samples, (2) to measure thermionic emission of the respective samples; (3) in each type of cathode, to correlate barium content and emission; (4) to study the influence, on barium content and emission, of (*a*) age of cathode, (*b*) anode material, (*c*) operating temperature, (*d*) variations in cathode coating, (*e*) composition of cathode support material (nickel of various grades, and platinum), and (*f*) treatment of the support material before coating.

Brazing Materials and Technique: A.W.S. Handbook

See abstract on p. 206.

Inert-Gas-Shielded Arc Welding of Metals and Alloys

See abstract on p. 232.

Argon-Arc Welding of Nickel and Other Metals

R. L. APPS and D. R. MILNER: 'Heat Flow in Argon-Arc Welding.' *Brit. Welding Jnl.*, 1955, vol. 2, Oct., pp. 475–85.

Heat flow in argon-arc welding, without filler metal, was investigated for aluminium, lead, nickel, copper and Armco iron.

Thioacetamide Separation and Determination of Nickel and Cobalt

H. FLASCHKA and H. ABDINE: 'Thioacetamide in the Separation and Complexometric Determination of Cobalt and Nickel.' *Chemist-Analyst*, 1955, vol. 44, June, pp. 30-1.

Ethylenediaminetetraacetic acid (E.D.T.A.) is a titrant of low selectivity, and when it is used special procedures must be employed if more than one metal ion is present in solution, e.g., the pH of the solution may be adjusted, an additional complexing agent may be employed to mask interfering ions, or special indicators may be used to enhance the selectivity of E.D.T.A. Such expedients are, however, of only limited application, and it is often necessary to resort to separation methods before undertaking titration.

For such separations thioacetamide has advantages, in that it precipitates metals as sulphides in a form free of contamination, and sufficiently coarse to be easily filtered and washed. It is, moreover, recognized that metal sulphides are among the least soluble compounds and that the decomposition products of thioacetamide do not interfere with subsequent operations.

Precipitation of metal sulphides from alkaline solutions involves some difficulties in manipulation, due to the fact that some of the sulphides tend to be colloidal. A previous paper by the present author showed, however, that manganese can be quantitatively separated without difficulty from alkaline earths by a single precipitation with thioacetamide, from an alkaline solution, and subsequently titrated with standard E.D.T.A. solution. This later paper describes similar procedure suitable for separation and complexometric titration of nickel and cobalt. Details of reagents required, and of analytical method for estimation of nickel, are given below:—

'*Thioacetamide Solution.* Dissolve 2 g. of reagent grade thioacetamide in 100 ml. of water.

'*E.D.T.A. Solution*, 0·100 *molar.* Dissolve 37·23 g. of disodium, dihydrogen, ethylenediaminetetraacetate dihydrate, and dilute to exactly one litre with water: (one ml. =5·869 mg. Ni
=5·894 mg. Co.)

'*Buffer solution.* Dissolve 13·5 g. of ammonium chloride and 88 ml. of concentrated aqueous ammonia in 250 ml. of distilled water.

'*Other reagents.* Ascorbic acid; 0·02 per cent. solution of methyl red in methanol; murexide indicator powder (one part of dye ground with 100 parts of sodium chloride); ammonium chloride; aqua regia; concentrated aqueous ammonia; saturated solution of bromine in concentrated hydrochloric acid; sodium acetate.

Procedure for Nickel

'Add 1–2 g. of ammonium chloride and an excess of thioacetamide solution to a neutral or slightly acidic solution of a nickel salt. Then add enough concentrated aqueous ammonia to make the solution strongly alkaline.

'Heat over a small flame. Near the boiling point, the solution will become brown, and soon a black precipitate will appear. Boil a few minutes to coagulate the precipitate, then allow to stand until the precipitate settles completely. Filter through a sintered porcelain crucible. If only a small amount of nickel is present, the precipitate does not settle appreciably, but it can be filtered by suction through the sintered crucible.

'No attempt should be made to remove the thin layer of sulphide adhering to the walls of the beaker. Wash the walls well and transfer these washings to the crucible. Remove the filtrate from the suction flask and dissolve the precipitate in the crucible by adding 2–3 ml. of a saturated solution of bromine in concentrated hydrochloric acid. Stir, to assist solution. Draw off the solution by vacuum and wash the

crucible well with water. Transfer the filtrate and washings to the original beaker and rinse its walls to insure solution of the adhering sulphide.

'Dilute with water to a total volume of 50 or 100 ml. and add a few crystals of ascorbic acid to reduce the excess bromine. Add a drop of methyl red solution and neutralize the solution with concentrated aqueous ammonia. Add 5 ml. of buffer solution and follow with enough murexide indicator powder to give a pure yellow solution. Titrate with 0·1 molar E.D.T.A. solution to a deep violet colour.'

Determination of Lead and Copper in Nickel

S. YOKOSUKA: 'The Analysis of Metallic Nickel. I. Determination of Lead.'
Japan Analyst, 1955, vol. 4, No. 4, pp. 99-103.
'II. Determination of Copper', *ibid.*, pp. 103-5.
Abstracts in *Analytical Abstracts*, 1955, vol. 2, Oct., Abs. No. 2686.

Determination of Nickel and Other Elements in Titanium Alloys

M. CODELL, G. NORWITZ and J. J. MIKULA: 'Analytical Chemistry of Titanium Alloys.'
Analytical Chemistry, 1955, vol. 27, Sept., pp. 1379-83.

This paper discusses the analytical chemistry of titanium alloys and correlates the many methods which have recently been published on the subject of analysis of such materials. The opening section of the review deals with methods of solution of samples, complexation, and separations, and with the application, in this field, of instrumental methods of analysis. This is followed by detailed consideration of methods which may be used for the determination of the following elements in titanium-base alloys: aluminium, boron, calcium, carbon, chloride, chromium, cobalt, copper, hydrogen, iron, magnesium, manganese, molybdenum, nickel, niobium, nitrogen, oxygen, phosphorus, silicon, silver, sulphur, tantalum, tin, titanium, tungsten, vanadium, zirconium.

The following information is given on estimation of *nickel:*

'Nickel can be determined colorimetrically with dimethylglyoxime without any separations, using an ammoniacal citrate solution (*Metallurgia*, 1954, vol. 49, p. 206; 'Final Technical Reports on Research and Development of Methods of Chemical Analysis for Titanium Metal and Alloys', published by *S. Tour and Company*, 1953 and 1954). For large amounts of nickel a sulphide separation of the nickel from an alkaline citrate medium, followed by the gravimetric determination of nickel as nickel dimethylglyoxime, is recommended (*Metallurgia*, loc. cit.). Nickel in titanium and titanium alloys can be determined polarographically from a pyridine-pyridinium chloride medium (*Anal. Chem.*, 1955, vol. 27, p. 729).'

Analysis of Light Metals and Alloys

See abstract on p. 215.

Determination of Traces of Nickel and Other Metals in Petroleum

L. W. GAMBLE and W. H. JONES: 'Determination of Trace Metals in Petroleum. Wet Ash/Spectrographic Method.'
Analytical Chemistry, 1955, vol. 27, Sept., pp. 1456-9.

Various investigators have reported that small amounts of metallic elements in crude petroleum and its products are of considerable significance in the petroleum industry. For example, the presence of vanadium in fuel oils is undesirable due to the corrosive effect of vanadium pentoxide on turbine blades and on fireclay brick, and trace amounts of nickel, vanadium, copper and iron in catalytic-cracking charge stocks contaminate the catalyst and cause greatly increased yields of gas and coke and lowered petrol production. Accurate analytical procedures are therefore of considerable importance.

The data presented in this paper confirm that trace metals in petroleum distillates are more completely recovered by a wet-ashing or partial sulphuric-acid decomposition method than by the conventional dry-ashing procedures. A wet ashing/spectrographic procedure, using magnesium nitrate as an ashing and spectrographic aid, has been developed, and by it nickel, vanadium and manganese can be accurately determined at 0·1-20 p.p.m. level, using samples of 10-50 grams.

It is anticipated that the method will be applicable also to determination of trace amounts of iron, sodium and copper when magnesium nitrate free of these elements becomes available.

Magnetic and Electrical Properties of Nickel Oxide

R. R. HEIKES: 'Relation of Magnetic Structure to Electrical Conductivity in NiO and Related Compounds.' *Physical Rev.*, 1955, vol. 99, Aug. 15, pp. 1232-4.

A qualitative theory is advanced to explain the insulating properties of NiO, and the theory is generalized to include all stoichiometric binary compounds which have a transition element as cation and an element from group V or group VI as anion. Correlation between magnetic and electrical properties is predicted. According to this theory, ferromagnetic compounds should be good electrical conductors, having a positive temperature coefficient of resistivity, whereas antiferromagnetic substances should be insulators, having a negative temperature coefficient. Available data confirm that such correlation of magnetic and electrical properties exists.

Heat of Formation of Nickel Carbonyl

I. SMAGINA and B. F. ORMONT: 'The Heat of Formation of Nickel Carbonyl.' *Zhur. Obshchei Khim.*, 1955, vol. 25, pp. 224-30; English translation in *Jnl. Genl. Chemistry* (*U.S.S.R.*), 1955, vol. 25, pp. 207-12.

The authors describe a new method of determination: the value obtained was $-44{\cdot}9 \pm 1$ kcal./mole. Details of procedure are given in *Chemical Abstracts*, 1955, vol. 49, Sept. 10, p. 11,386.

Adsorption of Chlorine Trifluoride on Porous Nickel Fluoride

R. L. FARRAR and H. A. SMITH: 'The Adsorption of Chlorine Trifluoride on Porous Nickel Fluoride.' *Jnl. Amer. Chemical Soc.*, 1955, vol. 77, Sept. 5, pp. 4502–5.

In a previous paper the authors had studied the kinetics of the reaction of chlorine trifluoride with nickel oxide and had shown that the product was a very porous nickel-fluoride powder which, from the evidence of weight-gain, appeared to possess an unusual capacity for adsorption of the reactant gas. In the present paper they report an investigation of the anomalous adsorption properties of the powder. It is shown that after the initial rapid physical adsorption the sample continued to adsorb chlorine trifluoride at a rate which followed the parabolic law. Anomalous values of surface area were obtained, as determined by low-temperature nitrogen adsorption, using the B.E.T. method. An explanation suggested by the authors involves diffusion of the sorbate molecules down the micro-channels between the crystallites of the porous particles.

Properties of Nickel Difluoride

E. CATALANO and J. W. STOUT: 'Heat Capacity of NiF_2 from 12° to 300°K. Thermodynamic Functions of NiF_2. The Thermal Anomaly Associated with the Antiferromagnetic Ordering.' *Jnl. Chemical Physics*, 1955, vol. 23, July, pp. 1284-9.

Heat capacity was measured calorimetrically over the range indicated.

Nickel Compounds in Detection of Formaldehyde

P. W. WEST and B. SEN: 'A New Spot Test for Formaldehyde.' *Analytical Chemistry*, 1955, vol. 27, Sept., pp. 1460–1.

The authors propose a new method for detection of formaldehyde, by means of a spot test on reagent paper which is prepared by impregnating filter paper in an equilibrium mixture of potassium tetracyanonickelate and dimethylglyoxime. Test procedure is detailed in the report. As little as 0·5 of formaldehyde can be detected by this method, which can be employed as a semi-quantitative procedure. Neither sulphite nor sulphide interferes, and tests with a large number of other organic compounds indicated no unfavourable effects.

ELECTRODEPOSITION AND OTHER COATING METHODS

Preparation of Metals for Electroplating: Evaluation of Surface Cleanliness by Radioactive Tagged Soils

J. W. HENSLEY and R. D. RING: 'Metal Cleaning Studies using Radioactive Tagged Soils.' *Plating*, 1955, vol. 42, Sept., pp. 1137–43.

Although published literature on metal-cleaning processes is relatively voluminous, little of it deals with quantitative studies of the actual cleaning processes and the mechanisms involved. (It should be noted that this matter is being investigated by the American Electroplaters' Society under its Research Project No. 12. Reports issued in this connexion have been abstracted in *The Nickel Bulletin* as published; see, for example, 1954, vol. 27, Nos. 1, 5 and 12, pp. 3, 91, 224,; 1955, vol. 28, No. 11, p. 183.)

It is pointed out that all the test methods which have yet been proposed for estimating the cleanliness of metal surfaces (reviewed by LINFORD and SAUBESTRE, *Plating*, 1950, vol. 37, pp. 1265–9, *ibid.*, 1951, vol. 38, pp. 60–5, 158–66) have inherent limitations with regard to sensitivity, accuracy, types of soil or surface which could be used, etc. It is suggested, however, and demonstrated by the tests reported in this paper, that radioactive-tracer techniques are promising for soil evaluation.

In order to provide, as quickly as possible, information of practical value, the initial tests made by the authors have been concentrated on study of removal of individual soil components most usually encountered in commercial plating practice, e.g., mineral oils, saponifiable oils, fatty acids, insoluble soaps, and particulate or smut-type soils such as finely divided carbon, metal, and oxide. To date, experiments have been carried out with radioactive tagged stearic acid, mineral oils, calcium stearate and carbon smut: for these substances suitable test procedures have been developed. Preliminary trials have been made with tagged clay and tagged calcium-carbonate particles, as representing smut-type soils.

Most of the work done has been with stearic acid: a first report on this work was made by the present authors in 1952 (see *A.S.T.M. Special Technical Publn.* 115, pp. 18–32; *Metal Finishing*, 1952, vol. 50, July, pp. 49–52, Aug., pp. 77–80, and *Plating*, 1953, vol. 40, p. 366). The paper now published covers additional tests with the stearic-acid soil and some experiments with a tagged mineral oil. The test coupons were of polished cold-rolled carbon steel, and the tagged soils were applied to the surface in uniform manner, using a machine which is described and illustrated in the paper. The cleaning media used were of commercial types and a study was made of the influence of cleaning time, concentration of cleaner, direction of current used for electrocleaning, addition of anionic surfactants to the alkali solutions, and current density. The effect of initial amount of stearic-acid soil was also evaluated, using three levels (34, 408 and 816 micrograms on a surface of a little more than one square inch). A series of graphs illustrates the observations made.

Although it is urged that full interpretation of the results of these tests in terms of practical commercial cleaning must await further work, the authors consider themselves justified in concluding that the principle of radioactive tracer examination of soil removal is satisfactory, and that further development will place at the disposal of the plater a reliable method of evaluating the surface cleanliness of the metals.

Anodic Etching Prior to Plating

F. G. BRUNE and V. L. MCENALLY: 'The Anodic Etch in Preparation for Plating.' *Plating*, 1955, vol. 42, Sept., pp. 1127-32.

The writers describe experiments made in development of procedure designed to ensure optimum adhesion of electrodeposited nickel (0·003 in. coating) on a steel bar 11 in. × 1½ in. × ¼ in. Adhesion was to be tested by bending the ¼-in. dimension 180° about a 1-in. radius, and reverse bending to the original flat form. The specification required that under such test no peeling or flaking of the coating should occur.

Experience with the successful use of a sulphuric-acid etch in the nickel-plating of steel bumpers, and good weathering properties observed in ferrous parts prepared by electropolishing, indicated the advisability of anodic etching treatment, and various procedures, using sulphuric acid, were considered. Since most of these processes called for the use of high current densities (125-200 amp./sq. ft.), their use for treating parts of the size in question would have necessitated a large power source and extensive cooling capacity. Consideration was therefore given to alternative etchants, and an epsom-salt*/sulphuric-acid solution was chosen. The preparatory cycle finally standardized was as follows:—

Alkaline, high-spray wash
Anodic electrocleaning at 75 amp./sq. ft.
Warm-water rinse
Cold-water rinse
Muriatic-acid dip, 10 per cent. by vol.
Cold-water rinse
Anodic etch, epsom salt/sulphuric-acid, at 50 amp./sq. ft.
Cold-water rinse
Nickel plating

Initial make-up of the bath, on a weight basis, is water 25, sulphuric acid 25, magnesium sulphate 50, per cent. About 20 per cent. of the tank volume is added as water and saturated with epsom salt, after which sulphuric acid and epsom salt are alternately added until the whole solution is made up. After analysis, water can be added to adjust the level, if such adjustment is required. In normal operation the etchant should be maintained in a condition of saturated solution. The solid phases known in the system involved are $Mg(SO_2).H_2(SO_4).3H_2O$ and $Mg(SO_4).3H_2(SO_4)$, and, due to the presence of these double salts the baths tend to be self-regulating, but periodic additions of sulphuric acid and epsom salt are necessary to maintain the concentration at saturation. The bath is operated at 50°-80°F. (10°-25°C.): at the higher end of this range rapid transfer from the etch tank, through the rinse and into the nickel tank, is essential. A maximum of 60°F. (15°C.) for the etch solution was found, in most cases, to be preferable. Drag-in of water should be held to a minimum, since the addition of epsom salts supplies a considerable amount of water of hydration.

**Magnesium sulphate.*

The following practical observations are made with regard to working conditions:—

In operation, usage of the solution is dependent upon drag-out. Operation in the conditions described required an additional 100 lbs. of epsom salt for each 350 lbs. of sulphuric acid used. Within the temperature range mentioned, about 40 oz./gal. of epsom salt is required to saturate the solution, and although it is possible to operate with lower concentration, results are less satisfactory. It is noted that up to 200 p.p.m. copper impurities do not plate out as an immersion deposit; that the solution will etch nickel parts which are being re-plated, and that it will operate with accumulations of 1 per cent. of nickel and 3·5 per cent. of iron.

It is emphasized that the epsom-salt/sulphuric-acid solution has the advantage of operating well at relatively low current densities (25-50 amp./sq. ft.); with this bath 25 amp./sq. ft. will produce results equal to those obtainable by etching with 200 amp./sq. ft. in a 25 per cent. by wt. sulphuric-acid solution. A further cost advantage is that with the epsom-salt/sulphuric-acid bath the voltage required to maintain high current densities is much less than that necessary with the straight sulphuric-acid bath.

It was found that in plating the bar parts described a 5-minute etch in the mixed solution was required to ensure adhesion which would satisfy the bend test. In processing parts which had become rusted the rust was removed by soaking in the muriatic-acid dip, and for each extra 5 minutes in that bath an extra minute of anodic-etch treatment was found to be desirable. The method described proved to be the solution of a problem presented by the call for production of an adherent nickel coating at minimum cost.

In considering the data obtained in the experiments reported, in association with published information on anodic-etching and other cleaning procedures, the authors reached the conclusion that classical concepts of 'cleanliness', 'active condition', and 'passive condition', as generally used, are outmoded. They posit an 'aqueous-film' concept, to serve as an explanation of the surface conditions occurring during preparation of metals for plating.

A.S.M. Metals Handbook: Revised Sections

See abstract on p. 205.

Bright Nickel Plating: Solutions, Technique, Properties of Deposits

T. E. SUCH: 'Bright Nickel-Plating Solutions: Their Choice, Control and Operation.' *Electroplating*, 1955, vol. 8, Sept. and Oct., pp. 308-15, 346-50.

This article comprises a useful review of the current stage of development with regard to bright and semi-bright nickel plating. In Part I the various types of bright nickel-plating solution are considered, with details of basis compositions, nature of primary and secondary brighteners employed, levelling action,

and the incorporation of anti-stress agents in the solutions. The relative advantages and limitations of cobalt-nickel and of organic-type bright-plating solutions are discussed, and the arguments which can be advanced for semi-bright deposits are reviewed.

The importance of routine control of bright-plating solutions is emphasized, and the methods used for maintenance of correct metal content, pH, and concentration of organic addition agents are indicated. In connexion with the effect of impurities, particularly in organic-type solutions, the author urges the more general use of accurate and reproducible methods of determining stress in the deposit, and its ductility, and the more meticulous keeping of records showing day-to-day variations in the electrodeposited products. A typical tally of the physical properties of cobalt-nickel deposits obtained from the same solution over a period of two months is given, to illustrate variations which may occur.

In connexion with the maintenance of bright-nickel-plating solutions, details are given of methods of carbon purification and procedures for removal of metallic contaminants of various types. This section also includes notes on purification of newly prepared solutions, and on the use of anti-stress agents.

Part II of the review deals with special features of plant required for electrodeposition of bright nickel, with the cleaning of the basis metals on which bright coatings are to be deposited, throwing-power problems associated with bright nickel plating, the use of wetting agents to obviate pitting, the bagging of anodes, and the treatment of passive nickel before chromium plating. Finally, brief notes are given on tests which may be applied to assess the quality of bright nickel plating: jet tests, microscopic tests, magnetic methods and other procedures for determination of thickness.

Protective Coatings, Metallic and Non-Metallic

R. M. BURNS and W. W. BRADLEY: 'Protective Coatings for Metals.' Published by *Reinhold Publishing Corpn., New York*, 1955.

This book is included, as No. 129, in the Chemical Monograph series of the American Chemical Society. It may be regarded as a revision, and extensively amplified, second edition of a monograph prepared in 1939, under the same title, by BURNS and SCHUH. Like the earlier edition, it is intended primarily to serve those who need to select protective coatings for various applications. The book does not purport to be a manual on production of coatings, but a considerable amount of information is given on this aspect, in order to provide the reader with a clear understanding of the nature of the respective forms of coating, why they behave in the way they do, and which type is likely to be best suited for individual applications.

The first three chapters are introductory, dealing with the principles of corrosion and corrosion control, with surface preparation of basis metals for covering with organic or inorganic coatings, and with various types of metallic coating and the way in which they are deposited. These chapters are followed by detailed consideration of individual aspects of the subject, e.g., sprayed metal coatings; zinc, cadmium, tin, nickel and chromium, copper, lead coatings; coatings of miscellaneous metals and alloys, and of noble and rare metals. This section of the book is completed by a chapter reviewing the methods of test applied to evaluate the properties of metallic coatings.

Three chapters are devoted to organic coatings, their compositions and characteristics, methods for evaluation of quality, and spheres of application. (This is one of the subjects on which the information has been considerably amplified in the second edition.)

Chemical-conversion and anodized coatings also are treated more fully than in the first edition, since much progress has recently been made in development of new types of coating and improvement of coatings known earlier. Special-purpose coatings, e.g., those used for temporary protection in storage or working of metallic materials or components, are considered, also vitreous and related coatings.

The book ends with discussion of corrosion inhibitors, e.g., in domestic-water supplies, brines and acid pickling solutions, and in liquids and vapour phases encountered in the petroleum, natural-gas and other chemical industries.

Each chapter is well documented by reference to selected literature, and the presentation throughout is clear and concise.

Steels and Plated Coatings for use up to 1000°F. (540°C.)

See abstract on p. 225.

S.A.E. Aircraft Research Seminar: Design, Materials, etc.

See abstract on p. 223.

Electroless Nickel Plating of Ceramics

P. H. EISENBERG and H. C. SCHNEIDER: 'Electroless Nickel Plating of Non-Conductors.' *Plating*, 1955 vol. 42, Oct., pp. 1268–70.

This report describes technique developed, by Sylvania Electric Products, Inc., for nickel-plating of ceramic discs required in metal-to-ceramic seals. The main features of the procedure were as follows:—

(1) *Degreasing of the non-conducting surface*, by immersion in an alkaline proprietary solution, and *chemical etching*. Both solutions varied according to the basis material to be plated: the final requirement was a surface chemically clean and uniformly etched. The authors illustrate an alumina surface, for which a steel-cleaning solution and a sulphuric-hydrofluoric acid etchant had been used.

(2) '*Seeding*', i.e., sensitization of the surface in preparation for plating. The medium used was a 150 g./L. solution of sodium hypophosphite, operated at 90°C. When the pores of the ceramic had absorbed the reducing solution the work was placed in the nickel bath and plated to the desired thickness.

(3) *Plating*. The solution (selected from among those

recommended by Brenner) contained (g./L.) nickel sulphate 30, sodium acetate 10, sodium hypophosphite 10. The pH was 4–6; temperature 80°–90°C. Good results were obtained, and with correct control the bath remained stable and produced consistently satisfactory deposits.

(A detailed account is given of the precautions taken in making up and purifying this solution, in order to ensure cleanliness. The authors attribute much of their success to this procedure.)

A note is added on the qualitative adhesion test applied to the nickel-plated ceramic parts.

Non-conductive powders (−325 mesh) were successfully plated by the same method, but attempts to sinter the coated particles indicated that further work is required in this connexion.

Tin-Nickel Alloy Plating

R. T. GORE: 'Tin-Nickel Alloy Plated Coatings.' *Materials and Methods*, 1955, vol. 42, Oct., pp. 102–5.

This review article is concerned with development, in the U.S.A., of the Tin Research Institute tin-nickel alloy coating process (for details see papers by PARKINSON, abstracted in *Nickel Bulletin*, 1951, vol. 24, No. 5, p. 101, and by DAVIES, abstracted in *Nickel Bulletin*, 1954, vol. 27, No. 5, p. 89). Much of the information given in the review now published is taken from these papers, and reference is made to applications in which the process is already being used or for which it shows promise. These include chemical-processing equipment, castings forming part of food-processing machinery, small parts which can be barrel plated, accessory parts used in the automotive industries and in small appliances, parts of television sets, and other electronic equipment.

Electrophoretic Deposition of Nickel and Other Metals

J. J. SHYNE, H. N. BARR, W. D. FLETCHER, H. G. SCHEIBLE: 'Electrophoretic Deposition of Metallic and Composite coatings.' *Plating*, 1955, vol. 42, Oct., pp. 1255–8.

Electrophoresis relates to the movement of charged colloidal particles, in a liquid, by application of an electrostatic field, e.g., in electrophoretic deposition two electrodes are immersed in a suspension and a potential is applied to the electrodes, resulting in formation of a deposit of the suspended material on one of them. Most of the commercially established applications of the process are concerned with deposition of non-metallic materials, but the principle has been developed, in the laboratories of the Vitro Corporation of America, for deposition of nickel, nickel-chromium and nickel-chromium-iron coatings on base metals. Techniques for bonding the coatings by (1) deposition of a hydrogen-reducible oxide, or (2) by electrolytic deposition of a metal through the pores in the coating, have also been evolved. The authors of this paper outline the theory of electrophoresis and report experiments in application of the process to nickel and nickel-alloy deposition.

NON-FERROUS ALLOYS

Ternary Nickel-Chromium-Carbon Alloys

W. KÖSTER and S. KABERMANN: 'The Ternary System Nickel-Chromium-Carbon.'
Archiv f.d. Eisenhüttenwesen, 1955, vol. 26, Oct., pp. 627–30.

The authors refer to earlier investigations of the ternary system, made by Murakami, Takeda, Mutsuzaki and Murase. The results of their own work, comprising microscopic and X-ray investigations, are in general basic agreement with those of previous reports, but differ in that only three (instead of four) carbides were found, Cr_3C_2, $Cr_{23}C_6$, and Cr_7C_3. It is found that with increase in chromium content the solubility of carbon in the γ solid solution decreases to zero. Up to about 6 per cent. of nickel is soluble in the carbides Cr_7C_3 and $Cr_{23}C_6$.

Grain-Boundary Diffusion of Nickel into Copper

S. YUKAWA and M. J. SINNOTT: 'Grain-Boundary Diffusion of Nickel into Copper.' *Jnl. of Metals*, 1955, vol. 7, Sept., Sect. 2; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 996–1002; T.P. 4053 E.

The relatively prolific literature of metallic diffusion includes few quantitative studies of the influence of the many variables involved. The present paper is a contribution to this aspect, comprising an investigation of the effect of the crystallographic orientation of the grain boundaries, and of temperature, on the extent of boundary diffusion of nickel into copper. The work involved three main steps: (1) production of grain boundaries of known crystallographic orientation, (2) determination of the extent of diffusion into the boundaries, and (3) analysis of the resulting data in terms of the usual diffusion concepts.

The stripping film technique of high resolution autoradiography was used to detect diffusion of a nickel isotope (Ni^{63}) into copper, over the temperature range 650°–925°C. Particular attention was given to grain-boundary diffusion.

The observations made (of which full details are reported) lead to the conclusion that the extent of nickel penetration along the grain boundaries of copper is dependent upon the degree of crystallographic misfit between the grains forming the boundary. Maximum penetration was found to occur at the point of maximum misfit.

The ratio of grain-boundary-diffusion coefficients to lattice-diffusion coefficients, at low concentrations of nickel, is of the order of 10^4–10^5 for the range 650°–825°C. and for grain-boundary angles of 10°–70°.

The activation energy of grain-boundary diffusion of nickel into copper decreases with increasing boundary angle.

Mechanism of Sintering: Study with Copper and Nickel Wires

See abstract on p. 206.

Self-Diffusion in Nickel-Gold Alloys

A. D. KURTZ, B. L. AVERBACH and M. COHEN: 'Self-Diffusion in Gold-Nickel Alloys.'
Acta Metallurgica, 1955, vol. 3, Sept., pp. 442–6.

This paper reports measurement of the self-diffusion rate of gold-nickel alloys as a function of composition (throughout the system), and of temperature down to 840°C. An autoradiographic technique was used to trace the diffusion of Au^{198}.

Young's Modulus of Nickel-Cobalt Alloys

M. YAMAMOTO and S. TANIGUCHI: 'The Δ-E Effect and Young's Modulus of Cobalt-Nickel Alloys.'
Science Reports, Research Inst. Tôhoku Univ., 1955, A, vol. 7, pp. 35–49 (in English).

Young's modulus (E) and its change on magnetization (the Δ-E effect) were measured on annealed nickel-cobalt alloys throughout the binary system, at ordinary temperature, using the method of magnetostrictive vibrations in fields up to 1000 Oersteds. An abstract of the main findings is given in *Metallurgical Abstracts*, 1955, vol. 23, Sept., p. 24.

Strength of Materials: Textbook

See abstract on p. 220.

Ferromagnetic Hall Coefficient of Binary Nickel Alloys

A. I. SCHINDLER and E. I. SALKOVITZ: 'Ferromagnetic Hall Coefficient of Nickel Alloys.' *Physical Rev.*, 1955, vol. 99, Aug. 15, pp. 1251–2.

Published data on the Hall coefficient have been re-examined for binary nickel-base alloys containing 10, 20 or 30 per cent. of copper, 8 per cent. of aluminium, 3 per cent. of silicon, or 3 per cent. of tin. The results are examined in the light of a theory of the Hall ferromagnetic effect advanced by Karplus and Luttinger (*ibid.*, 1954, vol. 95, p. 1154).

Influence of Nickel (and Aluminium) on Corrosion-Resistance of Titanium

S. YOSHIDA, S. OKAMOTO and T. ARAKI: 'Studies of the Corrosion-Resistance of Titanium Alloys. I. Corrosion-Resistance of Ti-Al and Ti-Ni Alloys.' *Jnl. Govt. Mechanical Laby., Agency of Industrial Science and Technology, Tokyo*, 1955, vol. 9, Mar., pp. 51–60.

Corrosion tests were made on titanium-aluminium alloys (1–5 per cent. aluminium) and on titanium-nickel alloys (nickel 1–10 per cent.), in various test solutions, at normal and at boiling temperatures. From the results the authors conclude that:—

(1) Addition of aluminium or of nickel much improves corrosion-resistance of titanium in the following reagents: hydrochloric acid (10%), acetic acid (99%), formic acid (25%), ammonia water (5%), potassium hydroxide (5%), ferric chloride (30%), and aluminium chloride (saturated solution).

(2) Addition of aluminium effects a fair degree of improvement in nitric-acid solutions, and nickel additions confer somewhat better resistance on titanium in oxalic-acid (saturated) solution.

(3) Neither aluminium nor nickel additions influence behaviour of titanium in aqua regia or in 3 per cent. chloride solution.

(4) Both elements, when added to titanium, have a deleterious influence on resistance to sulphuric- and hydrochloric-acid solutions, and nickel has an adverse effect on resistance to nitric acid.

Machining of Aircraft Gas-Turbine Components

See abstract on p. 227.

Nickel-containing Materials in Chemical Engineering: Review

See abstract on p. 236.

Cavitation Testing of Metals and Alloys

See abstract on p. 237.

Analysis of Light Metals and Alloys

H. GINSBERG: 'Analysis of Light Metals.'
3rd, revised and enlarged, edition.
Published by *Walter de Gruyter and Co.*, Berlin, 1955; 285 pp. Price 24·80 D.M.

The basic arrangement of the third edition of this well-established textbook is fundamentally different from that of the two previous ones. Whereas in the 1940 and 1945 editions the subject matter was planned according to types of analytical procedure, the division is now according to the materials analysed and, within those main sections, in alphabetical order of the constituents determined in each metal or alloy. It is anticipated that such re-arrangement will facilitate use of the book by practising chemists.

Introductory chapters deal with the taking of samples and preparation for analysis, solution of samples, and general and special analytical methods and apparatus. These chapters are followed by sections covering the analysis of aluminium and aluminium alloys, beryllium, magnesium and magnesium alloys, and titanium. Methods for determination of nickel in aluminium-base materials, by photometric estimation with diacetyldioxime and by gravimetric estimation as nickel diacetyldioxime, are included in the procedures described. A highly selective *bibliography* of textbooks and journals dealing with chemical analysis is added, also information on structural formulae for the most commonly used organic reagents.

It is emphasized that all the methods recommended have been well proved by many analysts, over periods sufficiently long to establish their reliability.

Determination of Nickel and Other Elements in Titanium Alloys

See abstract on p. 210.

Brazing Materials and Technique: A.W.S. Handbook

See abstract on p. 206.

Brazing of Titanium to Stainless Steel

See abstract on p. 234.

Overlaying of Steel and Cast Iron with High-Nickel Alloys

See abstract on p. 219.

NICKEL-IRON ALLOYS

Nickel-containing Alloys in Bimetal Combinations

W. RIENÄCKER: 'Bimetals.'
Zeitsch. f. Metallkunde, 1955, vol. 46, June, pp. 429–34: see also *Schweizer Archiv*, 1955, vol. 21, Sept., pp. 289–95.

Brief reference is made to 'bimetallic' composites in which one of the components is scarce or expensive and in which, therefore, the 'bimetallic' assembly is used in order to economize in use of this material, e.g., a contact spring in which the properties of a precious metal are required only at the point of contact, or the tips of fountain-pen nibs. The paper is concerned almost exclusively with the type of material more generally known as bimetals, in which two layers of different materials are bonded together throughout the length of the strip or other form. The function of such materials, in control by the influence of differential thermal expansion of the two members forming the bimetals, is discussed, and the compositions and properties of materials suitable for high- and low-expansion elements are reviewed. The importance of nickel-manganese-iron-base alloys as high-expansion and nickel-iron alloys as low-expansion elements is emphasized. Properties characteristic of the most generally used bimetals are tabulated.

Nickel-Iron-base Alloy Strip: S.A.E./A.M.S. Specifications

Three specifications issued by the SOCIETY OF AUTOMOTIVE ENGINEERS cover nickel-iron-base alloy strip in various conditions. The composition limits laid down in all three schedules are as follows: carbon 0·06 max., silicon 1·0 max., manganese 0·8 max., phosphorus 0·04 max., sulphur 0·04 max., chromium 4·9–5·5, nickel+cobalt 41·0–43·0 (cobalt, if determined, 1·0 max.), titanium 2·2–2·6, aluminium 0·30–0·8, per cent., iron remainder.

A.M.S. 5221 covers treatment and properties of this material in the solution-treated condition; *A.M.S. 5223* deals with material cold-rolled to 10 per cent. reduction after solution treatment, and subsequently precipitation-hardened, and *A.M.S. 5225* relates to the same material precipitation-hardened after cold-rolling to 50 per cent. reduction. All three specifications are dated Aug. 15, 1955.

Vacuum Evaporation of Thin Films of Magnetic Nickel-Iron Alloys

M. S. BLOIS: 'Preparation of Thin Magnetic Films and their Properties.' *Jnl. Applied Physics*, 1955, vol. 26, Aug., pp. 975–80.

A major difficulty encountered in the use of magnetic materials in high-frequency applications is that of increased eddy-current losses. The solution to this problem is usually sought by laminating the core material, but this method has approached its practicability limit so far as thin-rolled ribbon materials are concerned. These are now available in thicknesses down to approximately 10^{-4} in., where eddy currents are negligible at frequencies below 10 mc. The author of the present paper proposes further reduction in thickness of alloy sheets, by the use of a vacuum-evaporation process, in which both the magnetic alloy and an insulating material are deposited in situ, to build up alternating layers of magnetic and dielectric films.

By the technique described, it has been found possible to produce thin ferromagnetic films and laminated structures composed of such films. Individual thicknesses ranged from 1,000Å to 100,000 Å, with coercivities of 0·1–40·0 Oersteds. The materials used comprised various types of Permalloy and 50–50 nickel-iron alloys; microchemical methods were used to control the composition of the films to the required limits. Magnetic properties of the films and laminations were found to be uniform to within a few per cent. for any single batch of cores, but the results indicate that further work is necessary to improve batch-to-batch reproducibility.

The author discusses selection of substrate material (which is significant), properties required in dielectric materials used in association with the magnetic films, effect of annealing, and other factors influencing the behaviour of the evaporated films. A magnetic orientation method was employed to produce materials showing rectangular hysteresis loops. The conclusion is reached that the methods described, although not yet fully developed, offer promise for practical exploitation, as a means of meeting requirements specified for materials used in high-frequency applications.

Nickel-containing Materials: Review of Literature

See abstract on p. 236.

Nickel 'Ferrites'

W. A. YAGER, J. K. GALT and F. R. MERRITT: 'Ferromagnetic Resonance in Two Nickel-Iron Ferrites.' *Physical Rev.*, 1955, vol. 99, Aug. 15, pp. 1203–10.

Ferromagnetic resonance data are presented, as a function of temperature from 4·2°K. to 380°K. (−269° to +109°C.), in $(NiO)_{0·95}$ $(FeO)_{0·05}$ Fe_2O_4 and in $(NiO)_{0·75}$ $(FeO)_{0·25}$ Fe_2O_3.

See also next abstract.

R. M. BOZORTH, E. F. TILDEN and A. J. WILLIAMS: 'Anisotropy and Magnetostriction of Some Ferrites.' *Physical Rev.*, 1955, vol. 99, Sept. 15, pp. 1788–98.

Magnetic crystal anisotropy and magnetostriction were measured in single crystals of ferrites having compositions represented approximately by MFe_2O_4, where M represents manganese, iron, cobalt, nickel and zinc, in various proportions. Special attention is given to the effect of heat-treatment in a magnetic field.

CAST IRON

Austenitic S.G. Iron

F. G. SEFING: 'Nickel Austenitic Ductile Irons.' *Amer. Foundrymen's Soc.*, Preprint 55–32, May, 1955; 4 pp.
Reprint issued by INTERNATIONAL NICKEL CO., INC.

The author of this paper emphasizes the valuable combination of properties offered by magnesium-treated high-alloy cast irons, which are characterized by strength and toughness, with good resistance to heat, corrosion, and wear. Their excellent castability and machinability are further advantages.

Three types of S.G. high-alloy cast iron are considered, the compositions of which are shown below.

The mechanical and physical properties of irons of these types are compared with those of flake-graphite cast iron containing nickel 18–22, chromium 1·75–2·50, per cent., i.e., material similar, except in graphite form, to cast iron No. 2 in the table below. For properties see Tables II and III on p. 218.

It has been found that in commercial practice strength properties can be further increased by rapid freezing (as in metal moulds), followed by normalizing at 1700°–1900°F. (925°–1035°C.), a treatment which induces fine carbides: see Table IV on p. 219.

Machinability of the nickel-containing austenitic S.G. irons is affected to some extent by the amount of carbides present, which is also reflected in the hardness. At the lowest hardnesses and with few carbides in the structure, machinability is similar to that of ferritic S.G. irons of similar hardness. In the usual range of hardness (140–180 Brinell) machinability is broadly similar to that of the flake-graphite austenitic irons, and tool grinds, speeds and feeds recommended for such materials may be used for the S.G. grades.

Data on the high-temperature properties of the S.G. high-nickel alloy cast irons, and on their oxidation-resistance, demonstrate a marked superiority over the properties of flake-graphite irons of parallel composition. These qualities are leading to extended use in various process industries and in power plant. With regard to corrosion-resistance, their behaviour is approximately equivalent to that of corresponding flake-graphite irons.

Alloy Cast Iron for Elevated-Temperature Use

SOC. AUTOMOTIVE ENGINEERS: 'Alloy Iron Castings, Sand, Corrosion- and Heat-Resistant.'
A.M.S. Specification 5393, Aug. 15, 1955.

Cast iron specified as suitable for use in low-stressed parts, such as valve housings, in which moderate corrosion- and heat-resistance is required up to 1200°F. (650°C.), is of the following composition: carbon 2·4–2·8, silicon 1·5–2·8, manganese 0·8–1·6, phosphorus 0·30 max., sulphur 0·12 max., chromium 1·7–2·4, nickel 18·0–22·0, copper 0·50 max., lead 0·003 max., per cent.

Tensile and hardness properties are laid down, and it is required that the iron shall show an austenite matrix with uniformly distributed graphite flakes. Parts must be capable of being cooled to −75°F. (−60°C.) without the austenite transforming to martensite, and the parts so cooled must, after returning to room temperature, be sufficiently non-

Table I
Chemical Analysis Range of Austenitic Nickel S.G. Irons

	(1)	(2)*	(3) †	Type 2 Ni-Resist
Total Carbon ..	2·40-2·85	2·40-3·00	2·70-3·30	2·40-3·00
Silicon	2·00-3·00	2·00-3·00	2·00-3·00	1·00-2·50
Manganese ..	1·80-2·40	0·80-1·50	6·00-8·00	0·80-1·50
Phosphorus ..	0·10 max.	0·20 max.	0·20 max.	—
Nickel	21·00-24·00	18·00-22·00	10·00-12·00	18·00-22·00
Chromium ..	0·50 max.	1·75-2·50	—	1·75-2·50
Magnesium ..	0·05-0·15	0·05-0·15	0·05-0·15	—

* Corresponding to normal copper-free Ni-Resist.
† The S.G. variety of the non-magnetic cast iron known as No-Mag.

Table II

Mechanical Properties of Austenitic Nickel Ductile Irons

As-Cast Properties from Castings and 1-in. Keel Bars

	(1)	(2)	(3)	Flake-Graphite Type 2 Ni-Resist
Tensile strength, p.s.i. ..	54,000-65,000	55,000-69,000	48,000-60,000	25,000-35,000
t.s.i.* ..	(24·0-29·0)	(24·5-31·0)	(21·5-27·0)	(11·0-15·5)
Yield strength, 0·2% offset, p.s.i. ..	30,000-35,000	32,000-36,000	30,000	—
t.s.i.* ..	(13·5-15·5)	(14·5-16·0)	(13·5)	
Elongation, % in 2 in. ..	20-40	8-20	5-10	1-3
Proportional limit, p.s.i. ..	12,000-16,000	11,000-18,500	—	—
t.s.i.* ..	(5·5-7·0)	(5·0-8·0)		
Modulus of Elasticity, p.s.i. $\times 10^{-6}$ ..	15·0	16·5-18·5	—	15-16·2
Hardness, Brinell ..	130-170	140-180	140-180	130-160
Impact toughness, Vee notch, ft.-lb. ..	28	12	15-20	—
Shrinkage, in. per ft. ..	—	0·215	—	0·23
Relation between 1-in. and 2-in. Keel Bars of No. 2 Iron				
			1-in.	2-in.
Tensile strength, p.s.i. ..	—	—	60,500	54,500
t.s.i. ..	—	—	(27·0)	(24·5)
Yield strength, 0·5% offset, p.s.i. ..	—	—	35,100	34,250
t.s.i.* ..	—	—	(15·5)	(15·5)
Elongation, % in 2 in. ..	—	—	18·5	15

* to nearest $\frac{1}{2}$ ton.

Table III

Physical Properties of Austenitic Nickel Ductile Irons

	(1)	(2)	(3)	Flake-Graphite Type 2 Ni-Resist
Specific gravity	7·4	7·41	—	7·3
Density, lb. per cu. in. ..	0·268	0·268	—	0·264
Thermal expansion:				
Millionths per °F. ..	10·0-10·5	10·4	—	10·4
Millionths per °C. ..	18·0-18·9	18·7	—	18·7
Electrical resistivity, Microhms per c.c. ..	—	102	95	140
Magnetic permeability— H = 300 at room temp. ..	1·03	1·02-1·04	1·03	1·03

Table IV
Effect of Fine Carbides on Strength and Toughness
Metal-Mould Data from Commercial Castings

	Sand-Cast	Cast in Metal Mould: Reheated to 1850°F. (1008°C.) and cooled in air
Tensile strength, p.s.i.	55,000-69,000	75,900-83,500
t.s.i.*	(24·5-31·0)	(34·0-37·5)
Yield strength, 0·2% offset, p.s.i.	32,000-36,000	42,500-46,200
t.s.i.* ..	(14·5-16·0)	(19·0-20·5)
Elongation, % in 2 in.	8-20	13·5-30
Hardness, Brinell	140-180	165-190

* to nearest ½ ton

magnetic to prevent a small steel magnet from adhering to the casting.

Overlaying of Steel and Cast Iron with High-Nickel Alloys

S. LOW: 'High-Nickel Overlays on Ferrous Metals.' *Welding Jnl.*, 1955, vol. 34, June, pp. 571-2.
Discussion on the paper by PEASE *et al.* (*ibid.*, Jan., pp. 40-8, see *Nickel Bulletin*, 1955, vol. 28, No. 4, p. 77).

The authors had concluded, from a few exploratory tests with overlays on cast iron, that the usefulness of any of the high-nickel filler materials for deposition on cast iron was extremely limited.

This conclusion is challenged by the present writer, who states that 'many commercial applications of Monel overlays on cast iron indicate that high-quality, defect-free deposits can be made on both unalloyed and alloyed cast iron if a barrier bead of 'Ni-Rod 55' or 'Ni-Rod' is employed.' Stress-relieving treatment of the cast iron, prior to overlaying, is recommended, to minimize cracking, particularly for highly restrained sections requiring rather large overlays. Details are given of technique used for overlaying of cast iron with Monel: interfaces at various stages of overlaying are illustrated, and a typical application is shown, in which Monel is used on the seat of an automatic cone valve. It is stated that shear and tensile test results indicate that the weld-metal/base-metal bond strength is equal to the strength of the weaker material, i.e., the cast iron.

S.G. Iron for Dies and Tools in the Sheet-Metal Industries

A. B. EVEREST: 'Spheroidal-Graphite Cast Iron Dies and Tools for the Sheet-Metal Industries.'
Sheet Metal Industries, 1955, vol. 32, Nov., pp. 805-12; disc., pp. 825-8, 830.
Reprint issued by MOND NICKEL CO. LTD.; Publn. 931.*

After a review of the general use of cast iron for dies and tools, attention is directed to the properties of S.G. iron which are of value for such applications. Particular emphasis is laid on the usefulness of this material in the heat-treated condition. It is pointed out that the combination of high strength and wear-resistance, with good casting and machining properties, is of practical advantage in this connexion.

Typical applications of S.G. iron in dies and tools are discussed. These include large dies for the automobile industry (an application which is rapidly developing in the U.S.A.), tool sets for forming stainless-steel cabinets and utensils, drop-stamping and forming tools, and parts of bending machines, shear frames and other equipment used in the sheet-metal industries. Examples are given of substantially increased production-forming of stainless steel, as compared with that obtained with tools of the alloy flake-graphite cast irons previously used.

S.G. Iron in the Petroleum Industry

A. B. EVEREST: 'Spheroidal-Graphite Cast Iron. A New Material for the Petroleum Industry.'
Brit. Petroleum News, 1955, vol. 4, Autumn, pp. 38-43.
Reprint issued by MOND NICKEL CO., LTD.; Publn. 991.*

In introducing S.G. iron to engineers in the petroleum industry, an account is given of the history of development of the material, and some comparison is made of its properties with those of grey cast iron. Particular emphasis is laid on the versatility of the new iron and on the wide range of properties which can be developed by heat-treatment.

The review of the applications of S.G. iron in this industry begins by reference to uses in the field, where tough and rugged equipment is required, e.g., in pumping rigs. Attention is directed also to its suitability for piping and casing. Next, properties are discussed in relation to refinery equipment, with particular reference to toughness, shock-resistance, and ability to withstand conditions which might arise in a refinery fire. Tests on refinery valves, and thermal-shock tests, are recorded, together with results of general mechanical tests on valves.

* *We shall be pleased to supply a free copy of this publication.*

As an indication of the growing interest in the petroleum industry, mention is made of the fact that the National Fire Protection Association of the U.S.A. has recently accepted S.G. iron as a material for valves, accessories, fittings, pumps, etc., and has included it in the revised edition of N.F.P.A. Standard No. 58.

CONSTRUCTIONAL STEELS

Metallography of Delta Ferrite in Alloy Steels

See abstract on p. 227.

Rare-Earth Additions to Low-Alloy Nickel-containing Steels

H. SCHWARTZBART and J. P. SHEEHAN: 'Rare Earths Improve Impact Properties of 4330.'
Iron Age, 1955, vol. 175, May 26, pp. 103–6.

The article reports results of tests in which the influence of small additions of Mischmetall (lanthanum 30 min., cerium 45–50, didymium + yttrium 20–24, per cent.) was tested on low-alloy nickel-chromium-molybdenum steels. The main conclusion reached is that such additions increase the toughness of the steel, without affecting its hardness, and improve the ratio transverse: longitudinal properties.

Strength of Materials: Textbook

B. B. LOW: 'Strength of Materials.' 2nd edition, revised. Published by *Longmans, Green and Co., London, New York and Toronto*, 1955; 320 pp. Price 18/6.

The aim of the second edition of this textbook is essentially similar to that initially laid down in 1949, i.e., to give assistance to students and engineers who desire to study the simpler aspects of the theory of strength of materials, but who find the standard works on this subject too comprehensive. The author has included the elementary theory required for solution of practical problems, and theoretical discussion is, throughout the book, illustrated by examples of problems which would normally confront the engineer.

The second edition embodies two welcome additions: (1) a chapter on methods of test used for engineering materials and components, and (2) a useful, though necessarily incomplete, summary of the mechanical properties of metals, steels and alloys which are of interest in structural work. This last section includes reference to some of the most important types of plain and alloy steels (wrought and cast), copper and the principal copper-base alloys, aluminium alloys, magnesium and its alloys, nickel, nickel-copper-base alloys of the Monel group, nickel-chromium-base alloys of the Nimonic and Inconel series, and titanium alloys.

Structural Changes in Low-Alloy Heat-Resisting Steels during Creep

See abstract on p. 222.

Thermal-Fatigue Cracking in Steels

W. RÄDEKER: 'The Effect of Drastic Temperature Alternation on the Surface Condition of Steels.'
Stahl und Eisen, 1955, vol. 75, Sept. 22, pp. 1252–60; disc., pp. 1260–3.

In an earlier report (*ibid.*, 1954, vol. 74, pp. 929–43) the author had described thermal-fatigue tests in which specimens of steel were subjected to repeated rapid quenching from temperatures within the range 300°–700°C. Number and depth of cracks so produced were found to depend primarily on the number of quenches and the temperature from which the quench was effected. This paper is complementary, dealing with the influence of surface condition of the steels on susceptibility to thermal fatigue, and with other aspects.

It has been assumed that oxide layers, if present on the surface, tended, on cooling, to break up, and that on subsequent repeated heating of the steel there would be a gradual build-up of these oxide regions and ultimate penetration of oxide into the steel. The author demonstrates, however, that thermal cracking occurs in steel repeatedly heated to and quenched from temperatures too low to cause oxidation, e.g., 400°C. In this paper heating and quenching tests on various types of steel, having varying oxidation-resisting characteristics, are reported, to support this argument.

Tests in an argon atmosphere and on high-chromium oxidation-resisting steels showed that the presence of an oxide film is not an essential factor in thermal cracking, and that films once formed do not influence the progress of thermal fatigue. With heating temperatures below 600°C., and repeated drastic cooling, an austenitic 18–8 chromium-nickel steel gave much better resistance to thermal fatigue than ferritic-pearlitic steels, but when the upper-limit temperature was further raised the austenitic steel was more susceptible to cracking. Raising the temperature of the quench medium, i.e., making the temperature change at the lower end less drastic, diminished cracking. Deformation observed in repeatedly quenched specimens indicates that tensile stress arising from rapid cooling is the most likely cause of thermal cracking, a conclusion which was confirmed by other tests reported in the same paper.

Low-Alloy Steel for Pressure Vessels: Properties and Uses

Three papers in the *Welding Journal* of September, 1955, deal with 'T-1' steel for pressure vessels: see below:—

(1) W. d'O. DOTY: 'Properties and Characteristics of a Quenched-and-Tempered Steel for Pressure Vessels.'
Welding Jnl., 1955, vol. 34, Sept., pp. 425S–41S.

This paper gives extensive data obtained in laboratory tests on T-1 steel, which was developed to meet

the need for a constructional material, primarily for use in plate form, which should possess, in the quenched-and-tempered condition, a minimum yield strength of 90,000 p.s.i. (40 tons per sq. in.), satisfactory low-temperature toughness, and good weldability. In addition, it was laid down that the steel, in the heat-treated condition, must possess sufficient ductility to undergo bending to reasonable radii, have satisfactory machinability, and be amenable to gas-cutting without the necessity for special precautions. The composition found to give a steel satisfying these requirements is as follows:—carbon 0·10–0·20, silicon 0·15–0·35, manganese 0·60–1·00, sulphur 0·050 max.*, phosphorus 0·040 max.†, nickel 0·70–1·00, chromium 0·40–0·80, molybdenum 0·40–0·60, vanadium 0·03–0·10, copper 0·15–0·50, boron 0·002–0·006, per cent.

(2) L. P. ZICK: 'Design of Welded Pressure Vessels, using Quenched-and-Tempered Steel', *ibid.*, pp. 442S–8S.

Deals with design of vessels made in T-1 steel.

(3) L. C. BIBBER: 'Suitability of Quenched-and-Tempered Steels for Pressure-Vessel Construction', *ibid.*, pp. 449S–64S.

Report of tests on full-scale pressure vessels made from T-1 steel.

A.I.S.I. Standard Specifications for Low-Alloy Steels

'A.I.S.I. Standard Alloy Steel Compositions.' *Metal Progress*, 1955, vol. 68, Aug. 15, p. 120C.

List of compositions specified as at revision of February 1954. The nickel-alloy steels shown in the list include straight-nickel types containing up to about 5 per cent. of nickel, low-alloy nickel-chromium-molybdenum grades of the 3000, 4300, 9300 and 9800 groups, nickel-molybdenum steels of the 4800 series and leaner-alloy steels of the 8600, 8700 and T.S. series.

S.A.E. Aircraft Research Seminar: Design, Materials, etc.

See abstract on p. 223.

High-Expansion Nickel-Manganese Steel

See abstract on p. 235.

Steels for Use up to 1000°F. (540°C.)

See abstract on p. 225.

Cavitation Testing of Metals and Alloys

See abstract on p. 237.

Nickel-containing Steels in Chemical Engineering: Review

See abstract on p. 236.

* 0·040 per cent. max. for firebox quality.
† 0·035 per cent. max. „ „ „

Inert-Gas-Shielded Arc Welding of Metals and Alloys

See abstract on p. 232.

Brazing Materials and Technique: A.W.S. Handbook

See abstract on p. 206.

Brazing of Titanium to Steel

See abstract on p. 234.

HEAT- AND CORROSION-RESISTING MATERIALS

High-Temperature Alloys: Compositions and Properties

AMER. SOC. TESTING MATERIALS: 'Compilation of Chemical Compositions and Rupture Strengths of Super-Strength Alloys.'
A.S.T.M. Special Technical Publn. 170, 1955; 5 pp.

This publication, issued under the aegis of the High-Temperature Sub-Committee of the A.S.T.M. Committee on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, lists the names, nominal chemical compositions, and characteristic strengths, for rupture in 100 and 1,000 hours, of some 100 high-temperature metallic materials produced in the U.S.A. and of over 40 made in other countries (U.K., Germany and Russia). Since most of the alloys mentioned are proprietary types, the names of the probable patentees have also been recorded. Wherever possible, the properties given are average values for the respective materials as tested in the usual condition of heat-treatment: where data averaged on figures from several sources are not available, information from the makers of the materials, from the literature, or from private communications has been used.

Two points are emphasized:—(1) the compilation does *not* include the conventional ferritic, martensitic or austenitic stainless steels, but is restricted to the 'superalloy' type of material specially developed for high-temperature applications, and (2) the data should *not* be used for design purposes, since the creep and rupture strengths of the materials reviewed are much affected by processing and heat-treatment, an aspect which is outside the scope of the present survey. The values given are intended rather to give a general idea of the relative strengths of the respective materials. The sponsoring Committee announces that the compilation will be revised at regular intervals, and that its scope may later be widened. Comments and suggestions for modifications are invited by the Society.

Nickel-base Alloys for Use at High Temperatures

W. BETTERIDGE: 'Alloys for Use at High Temperatures.' *Brit. Jnl. Applied Physics*, 1955, vol. 6, Sept., pp. 301–6.

This paper is based on the Chairman's Address

to the Midland Branch of The Institute of Physics, delivered on November 9th, 1954.

The materials discussed are dealt with in two classes:—

1. Those primarily of value on account of their resistance to oxidation, e.g., 80–20 nickel-chromium alloys in which oxidation-resistance has been improved by the addition of small amounts of other elements, such as calcium, cerium, zirconium, thorium or silicon. The mechanism by which such improvement in oxidation-resistance is obtained is discussed by reference to life tests on typical electrical-resistance wires of nickel-chromium alloys. Mention is made also of iron-chromium-aluminium alloys, which have good oxidation-resistance, but are limited in usefulness by low strength at high temperatures and a tendency to brittleness.

2. Alloys which offer high resistance to creep and fracture at high temperature. The creep-resistance typical of ferritic steels, austenitic steels, and nickel-chromium alloys, and their rupture strength at high temperatures, are demonstrated by graphs.

In connexion with nickel-chromium-base alloys of the Nimonic series, it is shown that heat-treatment has a significant effect on high-temperature properties. Curves relating to Nimonic 95 (nickel-chromium-cobalt-base alloy) are used in illustration of the importance of thermal treatment.

The final section of the paper deals briefly with the fundamental mechanism of creep, with particular reference to the validity of the Andrade theory.

Nickel-Chromium-Cobalt-base Alloy: Jetalloy 1570

R. W. GUARD and T. A. PRATER: 'New Super Alloy Speeds Jet Progress.' *Iron Age*, 1955, vol. 176, Oct. 20, pp. 116–18.

This article describes the properties of a new alloy developed, under the name of Jetalloy, by the General Electric Company, Schenectady. Composition limits are given as carbon 0·17–0·27, cobalt 36·9–38·5, nickel 27·7–28·5, chromium 19·7–20·4, tungsten 6·3–7·3, titanium 4·0–4·5, iron 1·5–2·8, per cent.

With regard to composition, the following points are noted:—the alloy is niobium-free; molybdenum is slightly less effective than tungsten in improving rupture strength, but its effect on ductility at rupture is considerable; the iron content has a marked effect in rupture strength after any given heat-treatment, and lowering of strength in higher-iron alloy was found to be associated with formation of a discontinuous lamellar grain-boundary precipitate.

In pilot-plant studies of heat-treatment the aim was to secure properties optimum for aircraft gas-turbine blading. The effect of various solution and ageing treatments was therefore assessed on the basis of high-temperature stress-rupture and fatigue tests. The results indicated 2150°F. (1175°C.) as the optimum temperature for solution treatment, and ageing at 1650°F. (900°C.) was found to ensure the required combination of strength and ductility. Notch-rupture tests at 1200°–1700°F. (650°–925°C.) showed that the alloy is notch-ductile at all temperatures above 1350°F. (730°C.). Deformation measurements made during stress-rupture tests indicate that variation in creep properties runs roughly parallel to that found in rupture. Specimens subjected to the standard heat-treatment showed outstandingly good fatigue strength at 1500°F. (815°C.), and notched-fatigue tests on bars having a stress-concentration factor of 2·6 indicated that the alloy is notch-ductile in fatigue as well as in stress-rupture.

Ternary Nickel-Chromium-Carbon Alloys

See abstract on p. 214.

Gas Turbines and Jet Propulsion: Textbook

G. G. SMITH: 'Gas Turbines and Jet Propulsion.' 6th edn. revised and enlarged by F. C. SHEFFIELD. Published, for *Flight*, by *Iliffe and Sons, Ltd., London; Philosophical Library, Inc., New York;* 412 pp. Price 35/-.

The earlier edition of this well known textbook was designed 'to present the most informative review possible of the gas-turbine situation as it existed in 1949.' The intervening years have seen substantial progress with regard to the gas turbine in aircraft, and have also witnessed the spread of this form of motive power into other fields. Such widening of interest is reflected in the subject matter of the sixth edition, which takes account of major developments of design and materials associated with the respective fields of application. The book retains its position as an authoritative account of early developments and subsequent progress.

Structural Changes in Low-Alloy Heat-Resisting Steels during Creep

F. WEVER, A. KRISCH and H. J. WIESTER: 'Changes in the Structural Condition of Chromium-Nickel-Molybdenum Steels during Long-Term Creep Tests at 500°C.' *Archiv f.d. Eisenhüttenwesen*, 1955, vol. 26, Aug., pp. 463–74.

It has been observed that from time to time some low-alloy steels, e.g., screw steels, break at a relatively early stage in elevated-temperature service, and that the fracture is predominantly intercrystalline. Such failure may occur even in steels which have satisfied the accelerated D.V.M. creep test laid down in D.I.N. specification 50 117. These observations indicated the need for long-term creep tests, and this paper reports such tests, made at 500°C., for periods up to 16,000 hours, on steels of the following composition: carbon 0·04–0·30, nickel 1·4–1·6, chromium 0·5–0·9, molybdenum 0·7–0·9, per cent. The steels were subjected to test in various conditions, i.e., after oil- or water-quenching, followed by tempering at various temperatures, and after isothermal treatments producing an intermediate structure. Much detailed information is given on the structures and properties of the steels in the initial conditions and after test for various periods. Comparisons are made of behaviour in the D.V.M. creep test, at 500°C., and under long-time test at the same temperature.

Observations on structures and on fracture surfaces, and information derived from analysis and X-ray study of carbides isolated from the steels, are correlated with creep behaviour.

The following are among the principal conclusions drawn:—

Tempering temperature and resulting carbide formation are the major factors determining the creep properties of the steels: the influence of the phase formed at the γ-α transformation (martensite or intermediate structure) is of much less significance. In all the steels examined, specimens which had been tempered, after quenching, at 570°C. or had been isothermally transformed at 350° or 450°C., showed a high creep limit in the accelerated test, and good creep strength in the 1,000-hour test, but in all cases fracture was intercrystalline and occurred without much preliminary deformation. Tempering at 620°-660°C., after quenching, resulted, however, in poor values in the D.V.M. test and a reduced creep strength in the 1,000-hour test, but the fracture occurred throughout the sample, with satisfactory elongation and reduction in area. Examination of carbides isolated from the steels leads the authors to explain the high creep-resistance of the steels which had been either (*a*) tempered at 570°C., or (*b*) isothermally transformed at the lower temperatures, to the fact that during long-time creep testing at 500°C. there is a precipitation of very finely divided Mo_2C. Since such precipitates start to be detectable only after more than 500 hours at that temperature it may be assumed that the high creep-resistance is associated with a preliminary or embryonic condition preliminary to the precipitation, which, although not detectable by carbide isolation, nevertheless enhances creep-resistance at quite an early stage. (See also confirmation of these observations in the paper by WEVER and SCHRADER, reported in the following abstract.) In steels tempered in the higher range (620°-660°C.) the Mo_2C precipitate has been to a large extent already formed during the tempering treatment and the precipitate occurs in coarser form. There is simultaneously considerable molybdenum-impoverishment of the matrix and this is accentuated by further precipitation of the carbide during creep at 500°C. Such impoverishment, and the resultant lessening of the precipitation possible during creep, would explain the lower creep strength of the specimens tempered at the higher temperatures.

Variation in creep strength is consistently related to the variation in fracture habit. The higher creep-resistance of the untempered specimens and of those tempered at 570°C. makes it possible for the interior of the grains to bear high stresses without deformation, and flow therefore occurs preferentially in the grain boundaries and finally leads to intercrystalline fracture before the interior of the grain is much deformed. In specimens tempered in the higher range (620°-660°C.) the lower creep strength results in deformation of the grains themselves under lower stresses; the load on the grain boundaries is correspondingly lower, so that fracture of these boundaries does not occur even after long periods.

See also—

F. WEVER and A. SCHRADER: 'Electron Microscope Studies of the Structural Change in a Chromium-Nickel-Molybdenum Steel during Long-Time Tensile Test at 500°C.', *ibid.*, pp. 475-81; disc., p. 481.

This paper, complementary to the preceding one, reports closer investigation of the structure of one of the low-alloy steels which were characterized by tendency to brittle fracture. The composition is given as carbon 0·14, nickel 1·6, chromium 0·77, molybdenum 0·94, per cent. It was examined after creep testing in the conditions produced (*a*) by air cooling from 930°C. followed by tempering at a low temperature (570°C.), and (*b*) by oil-quenching followed by tempering at 570° and at 640°C. For purely structural examinations, specimens which had been air-cooled from 930°C. and tempered at 640°C., and specimens water-quenched from 930°C. and tempered at 660°C., were also included.

The observations made confirm that in specimens tempered at 570°C. (after air-cooling or oil-quenching) the fine precipitate of Mo_2C formed only during creep testing at 500°C. and that even after heating at that temperature for 9,677 hours there was hardly any coarsening of the particles. However, the associated decomposition, which either accompanied or preceded the precipitation, caused bright, blurred patches in the ferrite. At the crystal boundaries of the former austenite grain boundaries the precipitated carbides were coarser. In specimens oil-quenched and subsequently tempered at a higher temperature (640°C.), the Mo_2C carbide precipitate was formed, in correspondingly coarser form, during tempering, and with prolonged tempering precipitation continued. The bright patches in the ferrite were not found in these specimens. In addition, there were coarser carbide particles at the former austenite grain boundaries: these were already present after tempering and did not alter on prolonged heating.

The observations made give strong support to the assumption that the very clearly marked difference in creep behaviour between the steels tempered at the lower and the higher temperature is attributable to the type and amount of Mo_2C present. The extent to which the difference in arrangement of the carbides at the former austenite grain boundaries affects fracture will require further investigation.

S.A.E. Aircraft Research Seminar: Design, Materials, etc.

A series of papers presented at the Aircraft Research Seminar organized by the Society of Automotive Engineers in December 1954 dealt with recent progress and the current stage of development in design and the use of metallic and non-metallic materials. Authors and titles of the individual contributions are shown below, with some notes on the content of papers relating to nickel-containing materials:—

M. R. KINSLER: 'The Aerodynamic and Power Plant Heating Problem in High-Speed Aircraft'; 7 pp. + figures.

C. S. DAVIS: 'Thermal Limitations of Common Aircraft Materials'; 4 pp. + figures.

C. W. ALESCH: 'Some Trends in Elevated-Temperature Airframe Materials'; 8 pp.

S. G. DEMIRJIAN: 'Technological Advancements in Jet Engine Materials'; 7 pp. + figures.

The author points out that construction of jet engines calls for assistance from almost every branch of metallurgy. This paper reviews a selection of alloys which are currently used in such power plant, in conditions involving high temperature and/or stress. The materials are considered as used in a typical jet engine built by the General Electric Company:—

Compressor blades. (High-chromium steels; titanium-alloy blades; methods of production used for compressor blades).

Combustion chamber inner liners. (Inconel currently used, but the trend to higher operating temperatures may necessitate a change, or use of ceramic coatings).

Nozzle diaphragm partitions. (Cast cobalt-base alloy, H.S.21, now used: ceramic coating being considered).

Turbine wheel. (In the G.E.C. engines this component is made up of a hub and shaft of low-alloy ferritic nickel-alloy steel, to which is welded a rim of 16-25-6 chromium-nickel-molybdenum steel.)

Buckets (*Rotor Blades*). Precision-forging procedure is outlined, as being the most generally used method of production, and the properties of the following materials are considered in relation to their ability to meet the requirements arising from the severe stress and temperature conditions to which these components are subject: Hastelloy B (nickel-molybdenum-base alloy), S-816 (cobalt-base alloy containing high percentages of nickel and chromium, together with smaller amounts of tungsten, molybdenum, niobium and iron), M-252 (nickel-base titanium-hardened alloy). The nature of failures which have been encountered in blades during service are briefly discussed (stress-rupture and fatigue). The current trend is stated to be towards more complex basic compositions and/or the addition of alloying elements, which tends to enhance difficulties of melting and fabrication. Vacuum melting is considered to offer promise, and development of roll-forging technique is advocated.

Tailcones. (A welded assembly of nickel-chromium titanium-stabilized stainless steel).

T. L. BURTON and A. RAWUKA: 'Hot Sandwiches'; 5 pp. + figures.

('Aircomb', resin-impregnated paper).

B. L. MANIRE, J. SNYDER and A. GUERREIRO: 'Transparent Enclosure Materials'; 4 pp. + figures.

Characteristics of the four groups of material used for transparent enclosures are discussed: acrylics, polysters, modified acrylics, and glass.

F. E. CLARK: 'High-Temperature Problems Associated with the Use of Rubber in Aircraft'; 8 pp. + figures.

L. O. CURTISS: 'Open-Flame Testing of Various Fibreglas Laminated Ducts at 2000°F.'; 6 pp. + figures.

M. TIKTINSKY: 'The Selection of Metals for Airframe Components as Affected by Operating at Elevated Temperatures up to 600°F.'; 10 pp. + figures.

J. W. HUFFMANN: 'Application of Metallic Materials for Aircraft Structures in the Temperature Range 600° to 1100°F.'; 11 pp. + figures.

Review of data available on the properties of metallic materials most useful for aircraft structures subjected to the range of temperatures shown. The types considered are:—

(1) *Martensitic steels* (low-alloy chromium and nickel-chromium-molybdenum steels, 5 per cent. chromium steel containing small amounts of tungsten and molybdenum, and 13 per cent. chromium steels containing small percentages of nickel and other elements).

(2) *Austenitic steels* (17-7, 18-10-Ti and 19-9-Mo-Ti).

(3) *Precipitation-hardening alloys* (17-7 P.H., a chromium-nickel steel containing aluminium; A-286, a 15-25 chromium-nickel steel containing small amounts of molybdenum, titanium and aluminium; Inconel X, nickel-chromium-base alloy containing niobium, titanium and aluminium).

(4) *Titanium alloys* (a binary alloy containing 8 per cent. of manganese is discussed as typical).

The properties of these materials are recorded, on the basis of information available from various sources. Data are presented on short-time tensile strength; effects of prolonged heating; short-time compression, shear and elastic moduli; creep and stress-rupture; influence of notches; fatigue. Some general observations are added with regard to the fabrication characteristics of the respective classes of material.

A. V. LEVY: 'Application of High-Temperature Materials to Aircraft Power Plants in the Temperature Range of 1200°-2400°F.'; 12 pp. + tables and figures.

Discussion in this paper is limited to materials for operation in turbojet engine afterburners, and those required in ramjets and rocket-engines.

Factors governing selection of alloys for high-temperature use are outlined, and metallic elements commonly found in high-temperature alloys are listed, with comments on their respective functions in the alloys. Materials which retain sufficient strength for service at the temperatures under consideration are based on compositions of which iron, nickel, or cobalt is the base. Details are given of the compositions and properties of typical materials of the three classes, e.g.,

Iron-base: Various grades of the chromium-nickel austenitic steels; stainless steels modified by molybdenum and tungsten; age-hardenable stainless steels,

Nickel-base Alloys: Inconel and Inconel X,

Incoloy, alloys of the Nimonic series, and nickel-molybdenum-base alloys of the Hastelloy types,

Cobalt-base Alloys: Complex alloys of the Multimet type, cobalt-base alloys modified by molybdenum, with or without niobium and tungsten, cobalt-base casting alloys of various Haynes Stellite grades.

These types of material are evaluated by the following criteria:—mechanical and physical properties required at service temperatures, critical alloy content, fabrication characteristics, scaling- and corrosion-resistance, cost. Factors influencing the elevated-temperature performance of metallic materials are then considered, with particular reference to melting point.

The second part of the paper is concerned with actual applications of the respective types of high-temperature alloys for parts of afterburners, ramjets and rockets, and the conditions in which they operate. The conclusion is reached that the applications of conventional high-temperature materials in this field are rapidly being pushed to the limit. New developments in materials and/or improved cooling methods will be necessary if advantage is to be taken of higher combustion temperatures in order to attain better performance.

J. V. LONG: 'Ceramic and Metal Coatings for High-Temperature Aircraft Materials';
6 pp. + tables and figures.

Metallurgical investigations have indicated that useful service of alloys at present known will be limited to operating temperatures of about 1800°F. (980°C.). The potential value of metals with specially high melting points, e.g., niobium and molybdenum, is being further studied, but in the one case scarcity is an adverse factor, and in the other poor oxidation-resistance.

Stabilization of surfaces by means of ceramic or metal coatings is being intensively studied in this connexion, and field tests have already indicated the value of this method of protecting hot parts of reciprocating jet engines. Fired-on ceramic, and diffused-aluminium coatings appear to be the most promising types: this paper describes and illustrates six internal power plants in which ceramic coatings have effectively prolonged the life of metallic materials or permitted reduction in the use of critical alloy elements.

In the Solar Aircraft Company's laboratories over 4,000 different types of ceramic-base coatings have been made: the author gives some account of the methods used for preliminary assessment of the usefulness of the respective types, prior to field test, and of results of field tests on selected coatings.

Although ceramic coatings provide good surface protection, resistance to thermal and mechanical shock presents a problem, also bonding of the ceramic to the metal base. Research to date indicates that such limitations may usually be overcome by use of cermet (ceramic-metal) combinations, in which the ceramic phase provides the high-temperature resistance and the metallic phase the required ductility and resistance to impingement erosion. Among the cermet coatings likely to prove useful is a nickel-magnesia coating, and a composite in which the metal constituent is Nicrobraz (nickel-chromium-boron alloy).

Among metallic coatings, the diffused-aluminium type appears most likely to give useful protection. Various processes have been developed for deposition of the aluminium, e.g., Calorizing, plating from the vapour phase of aluminium chloride, metal spraying, electroplating, cladding, casting. Coating is followed by diffusion treatment, to develop an intermetallic compound with the basis metal. Iron-aluminium, nickel-aluminium or cobalt-aluminium compounds are formed, according to the nature of the base: a diffusion coating on a nickel-base alloy is illustrated. Stress-rupture tests at 1500°F. (815°C.) and 35,000 p.s.i. (15·5 tons per sq. in.), on aluminized and unaluminized nickel-chromium-base alloy gas-turbine blades, show a tenfold increase in life for the coated part. The major limitation to development of aluminizing is at present the complexity of the processes required and the fact that it is difficult to coat parts of complex shape in which blind holes, grooves and sharp edges are encountered. A new process of aluminizing, similar in principle to enamelling (i.e., involving dipping and firing), promises to overcome some of these limitations. Research is particularly needed with regard to methods for coating protection of titanium and molybdenum: in both cases the major problem is to obtain a continuous coating without defects, and no entirely satisfactory method has yet been developed for protection of these metals.

Steels and Plated Coatings for Use up to 1000°F. (540°C.)

H. J. NOBLE and W. H. SHARP: 'Steels and Protective Treatments for Use up to 1000°F.'
Soc. Automotive Engineers, Preprint 529, June, 1955;
16 pp. + tables and figures.

The authors deal with their subject in three sections:
(1) factors involved in selecting suitable steels;
(2) stress-corrosion of martensitic steels, and
(3) protective coatings.

(1) *Factors involved in Selecting Steels*

Mechanical and physical properties, resistance to stress-corrosion, and production and fabrication characteristics call for consideration, also the strategic-element content. In general, the choice for service below 1000°F. (540°C.) lies among the hardenable low-alloy constructional steels, the martensitic chromium steels, and the austenitic stainless steels. Steels in these three categories currently used by Pratt and Whitney in aircraft are listed, their properties are indicated, and some notes are given on their respective applications. The influence of heat-treatment, on mechanical properties and fatigue of selected steels, is discussed, with curves. Particular attention is directed to the usefulness of martensitic chromium steels, which combine high strength with moderate resistance to rusting, but a warning is given with regard to the importance of correct heat-treatment, as affecting mechanical properties and corrosion-resistance. Some details are given of thermal treatments and pickling procedure found specially suitable for

such steels. The desirability of developing ferrite-free martensitic chromium steels is emphasized. Modified steels of this type which have been evolved to secure better high-temperature strength, e.g., those containing tungsten, molybdenum and vanadium, contain delta ferrite, which may have a serious effect on mechanical properties, and a study is being made of compositions further modified by additions of nickel, and having somewhat increased carbon contents, to counteract the influence of the ferrite-forming elements.

(2) *Stress-Corrosion*

Observations made, on service parts and in laboratory tests, are critically considered. Although the investigation was mainly practical in character, some attempt was made to determine the mechanism of stress-corrosion, and in this connexion the parts played by galvanic effects, and by hydrogen, are considered. The effect of hardness, tempering temperature, composition, and surface condition was also studied. The general conclusions drawn were that, for a given hardness, in martensitic stainless steels the steel which has been tempered at the highest temperature appears to have the best resistance to stress-corrosion: in the martensitic stainless steels examined no failure was experienced at a hardness of Rockwell C 26 or below. Tempering in the 300°-500°F. (150°-260°C.) range, or above 1150°F. (620°C.) appears to render these steels resistant to stress-corrosion. Stress-corrosion cracking in martensitic stainless steels is intergranular.

(3) *Protective Treatments*

(*a*) *Organic Coatings.* The authors consider that organic coatings have little service application for protection of low-alloy steels against heat and/or corrosion. A brief evaluation is made of elevated-temperature behaviour of four classes of organic coating.

(*b*) *Electroplated Coatings. Cadmium or zinc coatings* give good protection against corrosion, but both types oxidize at about 500°F. (260°C.), and become ineffective. A deterrent to the use of either of these metals as a coating is the risk of intergranular corrosion of the underlying steel, when stressed, by penetration of molten zinc or cadmium if the temperature rises above the melting point of the coating metal. The indications are that initial hardness of the base steel is an important factor in this connexion: Rockwell C 35 appears to be about the safe maximum. Such intergranular penetration may be caused also by coatings of tin and indium, and the same type of failure has been observed with plate combinations such as cadmium on tin, indium on silver, and tin on nickel.

Since a wide range of properties is obtainable in *electrodeposited nickel coatings*, this type of finish has useful applications for parts operating at normal and moderately elevated temperatures. The avoidance of tensile stress in the deposit is an important factor. Hard nickel plating gives excellent resistance to abrasion, and recent work has resulted in development of high hardness without the brittleness formerly associated with this type of coating. Heating reduces the high hardness and tends to lower the compressive stress: typical stress-hardness-temperature relationships are quoted.

Electroless nickel plating is considered to have a useful future for elevated-temperature use, in that deposits of this type, already of high hardness, harden further on heating. Maximum hardness is obtained by heating at 750°F. (400°C.), and some experiments have indicated that no loss in hardness occurs up to 1000°F. (540°C.), although there is some likelihood that continued heating at that temperature ultimately causes some reduction. An inherent advantage of the process is the possibility of producing a uniform coating on parts of complicated shape. Electroless nickel deposits appear to be as free from porosity as good-quality electrodeposited nickel coatings of similar thickness, and limited experience indicates good resistance to oxidation and corrosion up to at least 1000°F. (540°C.). Stress-relief treatments are desirable in order to eliminate any tendency to hydrogen embrittlement. Fatigue strength of steel appears to be more adversely affected by electroless nickel coatings than by coatings electrodeposited from a Watts-type solution, and the authors have found that heating at 900°F. (480°C.) does not improve fatigue strength as it does in steel coated with electrodeposits made from the Watts solution.

Chromium plating shows good abrasion-resistance, and, in adequate thickness, good oxidation- and corrosion-resistance, at temperatures up to 1000°F. (540°C.). Hardness of chromium coatings is not significantly lowered by heating at 750°F. (400°C.), being still above 800 D.P.N. Continued heating up to 1000°F. (540°C.) results in some loss in hardness: the effect on abrasion- or galling-resistance is not known.

Silver coatings are frequently used with success for applications requiring galling- and wear-resistance under dry-heat conditions up to 700°-800°F. (370°-425°C.). At temperatures in the region of 1000°F. (540°C.) oxygen diffuses through the coating and causes deterioration of the bond.

In the search for improved coatings, the authors have investigated several composite types, of which *nickel/cadmium* proved to have particularly promising properties. After electrodeposition of the final (cadmium) coating the plated part is heated at 620°F. (325°C.), i.e., slightly above the melting point of the cadmium, for about half an hour, causing diffusion of the cadmium into the nickel. It is stated that coatings of this nature have been in production use for more than two years. The principal advantages claimed for the diffused nickel/cadmium are:—

(*a*) Final thickness of the combined coating is less than 0·0005 in., an advantage in applications requiring close tolerances.
(*b*) It is effective in preventing corrosion at any temperature up to 1000°F. (540°C.).
(*c*) Where the base metal becomes exposed, due to scratches, etc., such coatings afford galvanic protection to practically the same extent as does ordinary cadmium plate.
(*d*) It does not cause intergranular deterioration under stress.

(*e*) It prevents stress-corrosion in martensitic stainless steels.

(*f*) It has fair to good anti-galling properties.

A warning is given that production of diffused nickel/cadmium coatings requires good control of the plating baths and of subsequent treatment.

Alloy Cast Iron for Elevated-Temperature Use

See abstract on p. 217.

Austenitic S.G. Iron

See abstract on p. 217.

Anodic Etching of Precipitation-Hardening Nickel-Chromium-base Alloys

Y. BAILLIE and P. GILLES: 'Anodic Etching Procedure Specially Suitable for Preparation of Precipitation-Hardening Heat-Resisting 80-20 Nickel-Chromium Alloys for Micrographic Examination.'
Comptes Rendus de l'Académie des Sciences, 1955, vol. 240, Mar. 28, pp. 1430-2.

The authors describe results obtained with an aqueous etchant containing hydrofluoric acid 5, propanol 1·85, glycerol 10, per cent. Examples are shown of the delineation obtained, by anodic etching in this solution, after preliminary mechanical and electrolytic polishing. The character of the precipitated phase and the arrangement of the precipitated particles are clearly defined, also the relative sparsity of particles of the precipitated phase in the grain-boundary regions. The treatment has the additional advantage that whereas in alloys prepared by simple electrolytic polishing the precipitate can be revealed only in specimens which have been subjected to intensive ageing (e.g., 300 hours at 900°C.), in specimens anodically etched, after electropolishing, the precipitate is revealed in alloys aged at 875°, or even 850°C.

Examination under the electron microscope indicates the reason for this improved delineation: the anodic etching outlines the particles of the precipitated phase without altering their form to any appreciable extent, thus facilitating measurement and detailed examination. The optimum current density for etching with this reagent is dependent on the stage of ageing of the specimen: it is normally between 20 and 50 milliamp./cm². Time of treatment is about 10-45 seconds for alloys of the Nimonic series. The procedure described is suitable also for preparation of specimens to be examined by electron-diffraction.

Machining of Aircraft Gas-Turbine Components

'Rolls-Royce Dart. The Manufacture of Components for an Airscrew Turbine Power Unit. Part II. Production of the Turbine Wheel and the Compressor Impeller.' *Aircraft Production*, 1955, vol. 17, Oct., pp. 386-94.

Continuation of the series of articles describing fabrication of the main components of the Dart engines. The low-pressure turbine wheel described is made from low-carbon high-chromium steel to B.S. specification S.62 and the compressor impeller is of material to D.T.D. 731, an aluminium alloy containing small amounts of copper, magnesium, iron and nickel.

'Part III. Machining the Rotating Guide Vanes, Burner-Nozzle Parts and Casing Guide Vanes', *ibid.*, Nov., pp. 442-50.

The guide vanes in the Dart engine are fabricated from a 60-ton tensile 3½ per cent. nickel steel. The production processes used in the manufacture of this component, with blades of aerofoil form and compound curvature, are unusual, since use is made of two divergent techniques, *viz.*, removing metal by straight machining, and manipulating metal by bending it to shape in a press. Details of machines used and operating procedure are given.

In connexion with the burner-nozzle components, particular attention is called to the precision required, as typical of work involved in production of parts for gas-turbine engines. A fully illustrated account is given of typical operations and machines used.

Carbon-Dioxide Coolant in Machining of Nimonic Alloys

'Machining Heat-Resisting Alloys with Carbon-Dioxide Coolant.' *Machinery* (*Lond.*), 1955, vol. 87, Sept. 16, pp. 665-8.

Reference has been made, in earlier articles in *Machinery*, to the use of the CeDeCut technique for cooling of cutting tools by means of liquid carbon dioxide, a procedure developed by the Carbon Dioxide Company, of Great Burgh, Epsom, Surrey. The present article describes the use of this process, in one of the factories of Rolls-Royce, Ltd., for machining of high-strength heat-resisting materials, such as Nimonic 95 (nickel-chromium-cobalt-base alloy), and R.ex 448 (high-chromium ferritic creep-resisting steel).

It is recorded that experience gained during six months' use of the CeDeCut process has proved that the technique affords definite advantages, both in prolonging tool life and in speeding up machining. Further, indirect, advantages include the cleaner working conditions prevailing when conventional coolants are not used, and the fact that, since the work is kept cool, close tolerance dimensions can be immediately checked, without the necessity of waiting for the work to cool down.

Metallography of Delta Ferrite in Alloy Steels

K. KUO: 'Metallography of Delta Ferrite.' 'Part I. Eutectoid Decomposition of Delta Ferrite.'
Jnl. Iron and Steel Inst., 1954, vol. 176, Apr., pp. 433-41.

A steel containing carbon 0·20, molybdenum 8·15, per cent. was studied.

'Part II. Formation of Delta-Eutectoid in 18-4-1 Type High-Speed Steels', *ibid.*, 1955, vol. 181, Oct., pp. 128-34.

The steels examined contained carbon 0·7, tungsten 18, chromium 4, vanadium 1·5, per cent. (approx.).

'Part III. Isothermal Transformation of Delta Ferrite in a Low-Carbon 27-5-1·5 Cr-Ni-Mo Corrosion-Resistant Steel', *ibid.*, pp. 134–7.

Parts I and II discuss the eutectoid decomposition of delta ferrite into an aggregate of austenite and carbide, as occurring in two high-alloy steels of different types. This aggregate, or delta eutectoid, is found to resemble pearlite, not only in appearance but also in the mechanism of its formation, with carbide as the nucleating phase. It was also suggested (in Part I) that an acicular aggregate of austenite and carbide, nucleated by austenite, and analogous to bainite, may form from delta ferrite within a temperature range somewhat lower than that of delta-eutectoid formation. Although theoretically possible, the occurrence of such an acicular aggregate in straight high-molybdenum or high-chromium steels is hindered in practice by the fact that the austenite becomes unstable as the transformation temperature is lowered.

It is known that nickel promotes formation of austenite and tends to stabilize austenite which already exists. For this reason, the author made further studies, using low-carbon steel containing chromium 27, nickel 5, molybdenum 1·5, per cent., as a material on which to study isothermal transformation of delta ferrite, with particular reference to formation of a bainite-like transformation product. (The steel is one which has been developed in Sweden mainly for use in the pulp industry. It has very good corrosion-resistance at normal temperatures, but at high temperatures formation of sigma phase occurs, with associated brittleness.)*

Specimens for investigation were heated for 10 minutes at 1250°C., to obtain a completely ferritic structure, and were then isothermally treated (in a salt or a lead bath, according to the temperature of treatment) at 50°C. intervals from 1100° to 600°C. The amount of transformation was estimated visually.

At the temperatures used, the ferrite partially decomposes, into an aggregate of austenite and carbide. When formed at temperatures above 900°C. this aggregate has the appearance typical of lamellar pearlite: when formed below 700°C. it is similar to acicular bainite, and in the aggregate formed at temperatures between 900° and 700°C. both structures are present. The isothermal-transformation diagram of the steel resembles that of austenite in a hypo-eutectoid carbon steel. (See also the following abstract with reference to formation of the bainite-like acicular aggregate in austenitic chromium-nickel-molybdenum steel.)

'Part IV. Decomposition of Delta Ferrite between 650° and 1000°C. in a Low-Carbon 18-10-3 Cr-Ni-Mo Corrosion-Resisting Steel', *ibid.*, Nov., pp. 213–18.

Optical and electron-microscopic examination revealed that in the early stages of transformation acicular austenite (sometimes containing carbide particles) formed along certain crystallographic planes of delta ferrite. This aggregate of austenite and the $(Cr, Fe, Mo)_{23}C_6$ carbide resembled bainite in appearance, and appeared as grooves on the polished surface.

Formation of sigma phase took place at a later stage, and occurred mainly, if not entirely, in the delta-ferrite pools which had not yet transformed into austenite. The pattern of the sigma was therefore governed by that of austenite.

The decomposition of delta ferrite into various products is discussed, in this paper, from the point of view of the chemical composition of these phases.

'Part V. δ-Eutectoid and the Constitution Diagram of the Fe-*M*-C System', *ibid.*, pp. 218–27.

The eutectoid decomposition of delta ferrite ($\delta \rightarrow \gamma +$ carbide) in vanadium, chromium, molybdenum and tungsten steels was correlated with the constitution diagram of the various Fe-*M*-C systems.

All papers in the series include many illustrations of typical structures.

Diffusion of Iron in Austenitic Nickel-Chromium Steel

V. LINNENBOM, M. TETENBAUM and C. CHEEK: 'Tracer Diffusion of Iron in Stainless Steel.' *Jnl. Applied Physics*, 1955, vol. 26, Aug., pp. 932–6.

Tracer diffusion of iron in 18-8 chromium-nickel steel was measured over a wide temperature range, by the surface-activity-decrease method, using radioactive Fe^{55}. It was found that when the grain-size of the steel is small grain-boundary diffusion contributes appreciably to the overall diffusion process. This effect decreases with rising temperature.

Tension-Impact Properties of Stainless Steels

A. CHOQUET, V. N. KRIVOBOK and G. WELTER: 'Tension-Impact Properties of Austenitic Stainless Steels at Ambient and Low Temperatures.' *Welding Jnl.*, 1955, vol. 34, Aug., pp. 361S–73S.

The aim of the tests reported in this paper was to obtain data of practical value in relation to the employment of stainless steels as materials of construction, e.g., in transport equipment, aircraft and structural applications. Composition and properties of the steels studied are shown in Tables I and II on p. 229.

At a later stage in the investigation a few tests were made on low-alloy steels (Corten and Yoloy).

Stainless-steel sheet of 0·082–0·070 in. thickness was used, and in view of the assumption that the ability of the steels to withstand dynamic stress is influenced by volume of metal involved in the test, five different gauge lengths were used in the experiments. The method of utilizing the differences so found, in calculating the dynamic properties, is indicated, and the test equipment and specimens employed are fully described and illustrated.

The series of tests made, and the main conclusions drawn from them, are shown below:—

(1) *Static Tension Tests*, on the base metals and on weldments, at ambient temperature and at −40°F. (−40°C.).

Samples of short gauge length (0·04 and ¼-in.)

* *See also reference to this steel on p. 231.*

Table I

Steel	C %	Cr %	Ni %	Mn %	P %	S %	Si %	Others %
17–7 Cr–Ni ..	0·08	17·04	7·82	1·15	0·031	0·030	0·40	—
17–7 Cr–Ni ..	0·09	17·02	7·47	1·32	0·03	0·02	0·32	—
17–7 Cr–Ni ..	0·097	17·12	7·13	1·20	0·029	0·020	0·44	—
16-16-1 Cr-Mn-Ni	0·08	15·64	0·93	17·17	0·025	0·006	0·50	N 0·16

Table II
Mechanical Properties

Steel	Temper	U.T.S.		Elongation in 2 in.
		p.s.i.	t.s.i.*	
17–7 Cr–Ni ..	annealed	120,000	53·5	43·0
17–7 Cr–Ni ..	¼ hard	127,000	56·5	45·0
17–7 Cr–Ni ..	½ hard	167,000	74·5	25·0
16–16–1 Cr–Mn–Ni	annealed	112,700 (long.)	50·5 (long.)	47·0 (long.)
		110,900 (trans.)	49·5 (trans.)	46·0 (trans.)

* To nearest half ton.

Butt–welded samples of these steels were also tested.

showed consistently higher strength, and, as the gauge length increased, the tendency, with few exceptions, was for the tensile strength values to be lower. Tensile strength, of both parent steel and of weldments, was higher at −40F. (−40°C.) than at normal temperature. Ductility was not drastically lowered in either case by the sub-zero temperature.

(2) *Tension-Impact Tests*, on the base metals and on weldments, at ambient temperature and at −40°F. (−40°C.), with additional tests on two steels at −110° and −300°F. (−79° and −184°C.).

(*a*) *Parent Steels*

Energy absorption was almost a constant value, independent of gauge length. In all the chromium-nickel steels, the higher the tensile strength (or 'temper') the higher was the tension-impact strength per unit volume at −40°F. (−40°C.), in comparison with the room-temperature values. The chromium-manganese steel showed no increase in tension-impact with lowering of temperature.

In the chromium-nickel steels, permanent (plastic) deformation accompanying impact was usually equal to or rather greater at −40°F.(−40°C.) than at ambient temperature, but in the chromium-manganese steel permanent deformation at the sub-zero temperature was less than that observed in normal-temperature tests.

Additional tension-impact tests were made, on one chromium-nickel steel (½-hard temper) and the chromium-manganese steel, at −110° and −300°F. (−79° and −184°C.). These showed that the further lowering of the temperature of test increases the energy required for rupture. At the lowest temperatures, i.e., in the region of liquid nitrogen, ductility at fracture remained reasonably high and there was no sign of 'brittle fracture.'

(*b*) *Weldments*

In terms of dynamic strength, the welds were inferior to the parent steels by a factor as high as 2·5 or 3. When rupture occurred in the weld the latter, as well as the base metal, showed considerable ductility. When rupture was in the heat-affected zone the ductility of the base metal was low, indicating the deleterious influence of the heating involved in welding. Dynamic strength of the weldments in the chromium-nickel steels was consistently higher at −40°F. (−40°C.) than at ambient temperature: in the chromium-manganese steel either the situation was reversed or the effect of temperature was negligible.

(3) *Studies of Distribution of Permanent Deformation (Elongation) under Impact Testing.*

In the static tests the permanent stretch (ductility), measured throughout the whole gauge length from shoulder to shoulder, was considerably above 10 per cent., which had been arbitrarily selected in these studies as a criterion of non-brittle material. The same pattern of ductility was obtained in tension-impact tests at ambient temperature and at −40°F. (−40°C.), and also in the two steels tested in the lower-temperature range (at −110° and −300°F.: −79° and −184°C.). Regions immediately adjacent

to welds showed lowered ductility, particularly in specimens of the higher-tensile steel.

High-Temperature Properties of H.N.M. Stainless Steel

E. A. LORIA: 'New Stainless Steels Qualify for High-Temperature Service.' *Iron Age*, 1955, vol. 176, Sept. 29, pp. 65–7.

Further to preliminary data on Crucible Company's H.N.M. steel (*ibid.*, 1955, vol. 175, Apr. 7, pp. 119–22; *Nickel Bulletin*, 1955, vol. 28, Nos. 6–7, pp. 115–16), information is now published on the high-temperature stress-rupture properties of the steel, with particular reference to the influence of heat-treatment on the values obtainable. A typical composition of H.N.M. steel is given as carbon 0·31, silicon 0·50, phosphorus 0·30, manganese 3·43, nickel 9·50, chromium 19·0, per cent.

Stress-rupture tests have been made, at 1350°F. (732°C.), on specimens solution-treated at 50°F. (28°C.) intervals over the range 1950°–2100°F. (1065°–1150°C.), oil-quenched, and aged at 1400°F. (760°C.) for 16 hours. The best combination of strength and ductility was obtained by solution treatment at 2000°F. (1095°C.). Ductility fell, strength rose, and hardness was increased as the solution-treatment temperature was increased to 2100°F. (1150°C.). Study of the influence of mode of cooling indicated oil-quenching as being most satisfactory: comparative data are given on specimens oil-quenched, water-quenched and air-cooled after solution treatment, and subsequently aged. The properties obtainable in H.N.M. steel are considered to be broadly equivalent to those typical of 16-25-6 chromium-nickel-molybdenum steel: a tabular comparison is made of stress-rupture properties of H.N.M., Type 316 (molybdenum-containing austenitic nickel-chromium steel), and 16-25-6. Tensile properties of H.N.M. steel at elevated temperatures (see Table above) show a satisfactory combination of strength and ductility, with particularly high yield strength.

Data on room-temperature properties show tensile strengths varying according to heat-treatment, from 153,000 to 180,000 p.s.i. (68·5 to 80·5 tons per sq. in.): the high strength of the steel is associated with precipitation of $Cr_{23}C_6$. It is suggested that the hardening producible is due to increased strain energy in the austenitic lattice, resulting from interstitially dissolved phosphorus.

A warning is given that although the steel contains more than 18 per cent. of chromium, its relatively high carbon content gives rise, on ageing, to precipitation of fine, randomly distributed carbides, and in certain media corrosion-resistance may thus be lowered.

Table I

Tensile Properties of H.N.M. Steel at Elevated Temperature

(Solution-treated for ½ hr. at 2000°F. (1095°C.), oil-quenched; aged for 16 hrs. at 1400°F. (760°C.), air-cooled)

Test Temperature		Tensile Strength		0·2% Yield Strength		Elongation	Reduction of Area
°F.	°C.	p.s.i.	t.s.i.*	p.s.i.	t.s.i.*	%	%
1000	540	102,000	45·5	74,000	33·0	17	43
1100	595	90,000	40·0	72,000	32·0	21	47
1200	650	81,000	36·0	69,000	31·0	23	47
1350	735	61,000	27·0	54,000	24·0	24	37

* To nearest half ton.

Resistance of Metallic Materials to Phosphoric Acid

J. BÜNGER: 'Corrosion of Alloy Steels and Nickel Alloys by Phosphoric Acid.' *Werkstoffe und Korrosion*, 1955, vol. 6, Aug.-Sept., pp. 369–74.

The literature on corrosion by phosphoric acid (reviewed as an introduction to this paper) indicates considerable gaps in knowledge.

The author reports a systematic investigation of the behaviour of various steels and alloys in contact with pure and commercial phosphoric acid, at various concentrations, and at various temperatures.

The materials tested included high-chromium steels, austenitic nickel-chromium steels of various compositions (including some containing molybdenum, with or without copper), nickel-molybdenum-base alloys, and a high-nickel alloy containing silicon and copper. The results are shown in a series of curves indicating the behaviour of the respective materials.

At high concentrations of acid only a 67-30 nickel-molybdenum alloy was completely resistant, but at lower concentrations some of the molybdenum- and copper-containing austenitic steels appear to be adequate, except at the highest temperatures investigated.

Corrosion of Metallic Materials in High-Temperature Water

R. FOWLER, D. L. DOUGLAS and F. C. ZYZES: 'Corrosion of Reactor Structural Materials in High-Temperature Water. II. Static Corrosion Behaviour at 600°- 680°F.' *Knolls Atomic Power Laboratory Report* 1248, Dec., 1954; unclassified 1955; 75 pp.

The work reported was done in support of advancement in design of water-cooled reactors. Static

corrosion tests were made at 600° and 680°F. (315° and 360°C.): the tests were for relatively short periods (500–1000 hours), but, in the light of other experience, it is believed that the times were sufficiently long to give reliable data on comparative corrosion rates of the materials tested. It is, however, emphasized that the results cannot be taken as final proof that a structural material is satisfactory for any particular application in a reactor.

The main conclusions drawn with regard to nickel-containing materials are summarized below:—

Niobium-stabilized Chromium-Nickel Stainless Steel and Straight 18-8 *Steel* effectively resisted water at both temperatures. After long exposure, specimens were found to show a dull black film, which could be only partially rubbed off. Corrosion in pure water, water containing hydrogen in any amount tested, *or* 0·02-M H_3BO_3, *or* LiOH up to 10^{-3}-M, *and* in 0·02-M ammonium borate, average 3-5 mg/dm²/500 hr. (It is noted that the absence of effect with added hydrogen is contrary to the findings of other investigators, who have reported that such additions conferred some protection.) Higher corrosion rates were observed in 5×10^{-3}-M LiOH and in 0·02-M H_3BO_3 adjusted with LiOH to pH 9·5.

Miscellaneous High-Nickel Alloys ('A' nickel, Illium, Inconel and Carpenter 20 alloy). In general, these materials react very slowly with pure water at 600°F. (315°C.), showing corrosion rates, by descaling, of about 5 mg./dm²/500 hr. Hydrogen in small amounts markedly reduced the extent of the reaction.

Iron-chromium-base alloys, zirconium and zirconium alloy, and carbon steels of various types were also tested.

Materials for Equipment used in Production of Wood Vinegar

L. WETTERNIK and H. ZITTER: 'Acid-Resisting Steels in Production of Wood Vinegar.' *Werkstoffe und Korrosion*, 1955, vol. 6, June, pp. 282–7.

Conditions obtaining during production of wood vinegar differ appreciably from those operative during manufacture of vinegar produced by fermentation (malt vinegar). In the latter case concentration of acid is rarely above 10 per cent., since the end product is table vinegar, whilst in production of wood vinegar not only is there a higher concentration of acetic acid, but many impurities are present, which make the solutions pronouncedly more corrosive. Such impurities comprise primarily the homologues of acetic acid, such as butyric acid, propionic acid and formic acid. Tarry and ash constituents, which may also be present, have, on the other hand, some inhibiting effect.

Investigations reported in this paper were put in hand as a result of corrosion which occurred during production of wood vinegar in plant made from 18-10-2 chromium-nickel-molybdenum steel. In an attempt to find a more resistant material, comprehensive tests were made, in conditions simulating those believed to obtain in service, on this steel and on three others; see Table below for detailed compositions.

Using the No. 4 steel as standard, steel 2 was designed to demonstrate the influence of increasing the chromium content; steel 3 had increased contents of both chromium and nickel, and steel 1 is a type developed and used in Sweden in plant handling pulp in the paper-making industry.

Table I

Steel	C %	Si %	Mn %	Cr %	Ni %	Mo %
1	0·04	0·73	0·80	27·25	4·60	1·47
2	0·12	0·20	1·32	27·60	10·59	1·87
3	0·08	0·20	1·39	27·56	21·40	1·84
4	0·08	0·44	0·92	18·90	11·46	2·20

The results of the tests, which were made both in boiling acids and in the corresponding vapour phases, lead to the conclusion that the 27-4·5-1·5 chromium-nickel-molybdenum steel shows best resistance to attack by crude acetic acid distillate containing about 70 per cent. of CH_3COOH, 0·5 per cent. of HCOOH and ashy constituents.

Resistance of Metallic and Non-Metallic Materials to Smoke from Locomotives

T. MARSHALL and R. M. SINCLAIR: 'Corrosion of Materials Subjected to Locomotive Smoke and Funnel Blast.' *Corrosion*, 1955, vol. 11, Sept., pp. 379t–82t.

This paper is contributed by members of the staff of the Dominion Laboratory, Department of Scientific and Industrial Research, New Zealand, and relates particularly to railway practice in that country, where locomotive sheds are built over sections of railway line, to house parallel rows of locomotives. A typical shed, measuring 300 × 60 ft., may accommodate three rows.

In sheds housing coal-burning or oil-burning locomotives rapid smoke extraction is essential for the safeguarding and efficiency of maintenance crews, and for this purpose simple roof louvers have proved

inadequate. Present practice is to use long, inverted U-ducts, suspended over the rows of locomotive funnels, to remove the smoke to vertical stacks constructed at intervals along the ducts and extending through the roof. Extraction depends on natural convection, but may be mechanically assisted.

Experience has shown that the following properties are essential in materials for the smoke ducts: (1) resistance to deterioration in the highly corrosive atmosphere, which is contaminated with steam, smoke, sulphurous fumes, fly ash and soot; (2) a fairly high strength/weight ratio, to minimize weight and cost of structures supporting the ducts, for which reason relatively thin sheet metal is advantageous; (3) ability to withstand direct funnel blast from locomotives at close range; (4) fire-resistance; (5) ability to give maintenance-free service for a period of some 20 years. It is also necessary that cost, in relation to effective service life, should be such as to make the use of the ducts economic. None of the materials yet used (mild steel, galvanized steel, asbestos-cement sheet) has proved satisfactory, and this paper reports tests made to assess the relative corrosion-resistance of various other materials which might be considered in comparison with that of the materials which had already been used.

The tests were made on mild steel, 18-8 chromium-nickel steel, 18-8-Mo steel, copper, aluminium and aluminium alloys, aluminium-clad aluminium alloy, galvanized steels, and steel coated with various protective media (including paints of many types, vitreous enamel, vulcanized rubber and proprietary bituminous coatings). All were tested in the form and surface condition most likely to be applicable to smoke-duct service. Rectangular panels of the test materials, mounted on hardwood frames, were exposed inside the smoke duct of a shed continuously used by coal- and oil-burning locomotives and were exposed in a manner simulating service conditions, e.g., subject to funnel blast, etc. Exposure periods varied from 7 months to 3 years, but were in all cases long enough to give indication of long-term behaviour.

Results obtained (detailed in the original) correlate well with those reported by other investigators (see *Corrosion*, 1950, vol. 6, p. 268 and *Jnl. Instn. Civil Engineers*, 1941, vol. 16, p. 65). The range of materials exposed in the present tests was wider than those used in earlier series. Austenitic nickel-chromium steels, especially the molybdenum-bearing variety, were highly resistant to corrosion, but cost has to be recognized as a factor limiting their large-scale application for smoke ducts. All the other unprotected metallic materials exhibited moderate-to-poor resistance to corrosion. On copper the corrosion was even and uniform, but high cost is again a disadvantage. Vitreous-enamelled steel, with the normal two-coat enamelling system, showed the best combination of corrosion-resistance, strength/weight ratio, freedom from brittleness, resistance to fire, and low cost. On the basis of these tests, the authors recommend, for smoke-duct construction, vitreous-enamelled steel, with stainless-steel bolts and vulcanized rubber washers.

Inert-Gas-Shielded Arc Welding of Metals and Alloys

A series of papers in the *British Welding Journal*, 1955, vol. 2, Oct., reviews recent progress and the current stage of development in inert-gas-shielded methods of welding of various materials. The scope of the respective papers is shown below.

J. HINDE and D. R. THORNEYCROFT: 'Welding of Nickel and High-Nickel Alloys by Inert-Gas-Shielded Arc Processes', pp. 411-19. Reprint issued by HENRY WIGGIN AND CO., LTD.; Publn. 976.*

The authors discuss the welding of high-nickel materials in two groups: (1) those used primarily on account of their corrosion-resisting characteristics, e.g., nickel, the Monel group, and Corronel B, and (2) alloys which are of outstanding interest in high-temperature engineering, e.g., the Nimonic series, and Inconel.

Practical recommendations are made with regard to heat-treatment (as affecting the stage during manufacture at which welding is carried out), surface preparation for welding, and technique suitable for inert-gas tungsten-arc welding of the respective alloys. This process is at present being applied principally to Nimonic 75, but is being developed for use with other alloys also. The authors discuss filler alloys, and tabulate conditions established, in laboratory tests, as suitable for use of the process in welding alloys of the groups named. Data are given also with regard to tensile properties obtainable on inert-gas tungsten-arc-welded joints of the nickel-base materials, and illustrations are shown of typical macrostructures of joints. For Nimonic 75 information on stress-rupture properties at 750°C. is also given. The effect of post-weld heat-treatment is demonstrated by reference to welds in K Monel and in Corronel B.

Brief reference is made to the inert-gas metal-arc process, which is at present only in the development stage. It is pointed out that this procedure has potential application for the deposition of corrosion-resisting overlay coatings as well as for welded joints.

L. H. ORTON and J. C. NEEDHAM: 'Some Electrical Aspects of Inert-Gas-Shielded Arc Welding', pp. 419-26.

The inter-relationships of the components associated with the electrical aspects of the welding process are indicated, and specific examples drawn from typical inert-gas-shielded arc-welding systems are used to illustrate these relationships. In connexion with the tungsten-arc process, attention is particularly directed to the question of arc re-ignition, and to the d.c. component and its suppression. In discussing the consumable-electrode processes, emphasis is placed on power-source requirements.

D. C. MOORE and E. A. TAYLOR: 'Welding of Copper and Copper Alloys by the Inert-Gas-Shielded Self-Adjusting Metal-Arc Process', pp. 427-42.

This paper reports an investigation on the application of the process to phosphorus-deoxidized copper and

**We shall be pleased to supply a free copy of this publication.*

a number of important copper alloys, including 70-30 and 80-20 cupro-nickels, nickel-containing bronzes, aluminium bronze, phosphor bronze and other copper-base materials. The experiments described have led to determination of optimum metal transfer in argon, using filler wire of varied composition. The use of nitrogen-shielding for welding copper was also studied.

Weld quality was assessed by radiographic and metallographic examination, which showed that, in all the alloys examined, sound, strong welds can be obtained by this process. With copper and the cupro-nickel alloys it is necessary to use special filler wire, containing small amounts of powerful deoxidants, in order to prevent porosity. It is concluded that the inert-gas-shielded metal-arc process has marked advantages by comparison with other fusion-welding methods, and that full commercial exploitation is warranted.

F. G. C. SANDIFORD, R. T. WEATHERSTONE, J. E. HOOPER, K. H. McDOWELL and L. CAMIDGE: 'Inert-Gas-Shielded Arc Welding in the Gas-Turbine Industry', pp. 443-55.

It is pointed out that although the aircraft field represents only a small section of the industries in which welding is an accepted method of fabrication, it is nevertheless a branch in which current development is very rapid, and, that with the trend towards thinner and stronger structures, welding is becoming increasingly important. Moreover, the work done, particularly on aircraft gas-turbine components, is of so highly specialized and precise a nature as to call for materials and technique as nearly perfect as can be achieved.

This paper comprises a critical and comprehensive survey of some of the aspects of welding involved in such work, and of difficulties experienced by various branches of a typical gas-turbine manufacturing group (Bristol Aeroplane Company, Ltd.). The subject is dealt with in sections covering, respectively:

(1) Development and welding research, based on work during the war and post-war periods.

(2) Metallurgical experience with the various materials handled in connexion with aircraft gas-turbine construction (mild steel, carbon and low-alloy steels of the manganese, chromium-molybdenum and boron-containing manganese-molybdenum types); austenitic corrosion- and heat-resisting steels; martensitic high-chromium steels; nickel-base alloys (Nimonic 75, 80 and 90); aluminium alloys, and titanium. It is emphasized that current trends are towards the use of higher-strength materials, in thinner gauges, necessitating even stricter control of thermal effects, and introducing specific difficulties in welding. These are now under intensive study.

(3) Process tooling, application and equipment. Problems of design, of adaptation of equipment for specialized requirements, and of operating technique for material of varying shape and gauge, are discussed, with comment on some limitations of current practice.

(4) Electrical aspects of equipment: service and maintenance.

(5) Methods used for assessment of weld quality and the factors affecting such assessment.

A. L. HALE: 'Some Factors Affecting Design of Aluminium-Alloy Fabrications Welded by the Inert-Gas-Shielded Arc Process', pp. 455-8.

P. BRADLEY: 'Testing and Inspection of Welds in Aluminium and Aluminium-Alloy Plate made by the Inert-Gas-Shielded Welding Processes', pp. 459-63.

J. G. YOUNG: 'Economics of the Joining of Aluminium and its Alloys by the Inert-Gas-Shielded Arc Welding Processes', pp. 463-70.

Welding of Austenitic Niobium-Stabilized Stainless Steel

J. M. PARKS: 'Welding Type 347 Stainless Steel for 1000°F. Turbine Operation.' *Welding Jnl.*, 1955, vol. 34, June, pp. 568-70.

Note contributed as commentary on paper by CURRAN and RANKIN: (*ibid.*, Mar., pp. 205-13; see *Nickel Bulletin*, 1955, vol. 28, No. 5, pp. 96-7). The writer proposes a mechanism relating hot-cracking with the composition of 18-8 chromium-nickel steel, with particular reference to build-up of silicon and phosphorus concentration in the weld metal during cooling. The significance of the carbon/silicon ratio is discussed.

Moisture in the Coatings of Austenitic Welding Electrodes

K. P. JOHANNES, D. C. SMITH and W. G. RINEHART: 'Coating Moisture Investigations on Austenitic Electrodes of the Modified 18-8 Type.'
Welding Research Council, Bull. No. 21, Feb., 1955; 18 pp.

In recent years considerable attention has been focused on the influence of moisture in the coatings of metallic-arc welding electrodes, particularly those of low-hydrogen and stainless-steel types. Research has been devoted mainly to determination of the effect of moisture on usability of the electrodes and on their storage life. This paper deals with another aspect, *viz.*, moisture exchange under various conditions of temperature and relative humidity. Conditions encountered in the use of welding electrodes may be such that appreciable amounts of moisture could be absorbed, and the relative capacity of various electrodes to absorb under such conditions is a factor of practical significance. Further objects of the present work were to determine the treatment required to restore electrodes to their original condition after absorption of moisture, the conditions of temperature and relative humidity necessary to prevent stored electrodes from absorbing harmful amounts of moisture and, finally, to assess significant differences which might exist between lime-type and titania-type coatings with regard to moisture absorption and remedial treatment. Simultaneously, an investigation was made of the effect,

in the welding of armour plate, of moisture in the coatings of electrodes of similar 18-8 chromium-nickel steel. The results of these tests were used as a guide in establishing safe values of moisture content below which there are no deleterious effects on usability. Three types and three commercial brands of modified 18-8 electrode were used and the moisture absorption was measured at temperatures of 75°, 85° and 100°F. (26°, 30° and 38°C.) and at relative humidities of about 50, 72, 82 and 96, per cent. Illustrations of the humidity cabinet and of the apparatus used for determination of rate of moisture absorption are shown in the paper.

It was found that the rates of absorption varied with the different brands of electrode, and that the most pronounced variations were at the higher humidities. Temperature proved to be a potent factor in influencing rate at which moisture was picked up, but within the range of temperatures used in this investigation the total amount absorbed at equilibrium was found to be determined by relative humidity.

Remedial treatment for moisture-damaged electrodes was studied by heating at 250°, 350°, 450°, 550° and 650°F. (120°, 175°, 232°, 288° and 343°C.), electrodes having initial moisture contents, in the coatings, of 3·00–4·00 per cent. Although there was considerable variation in the reaction of the individual types, it is concluded that treatment at 300°F. (150°C.) in a well ventilated oven, for about one hour, will reduce the moisture content to a safe value. Prolonged drying at lower temperatures (250°–300°F.: 120°–150°C.) is apt to cause some coatings to become brittle and crack.

Electrodes stored in open containers at a relative humidity of 50 per cent. or below, at room temperature, will not absorb a harmful amount of moisture. In storage conditions where temperature only is controlled, 150°F. (65°C.) appears to be sufficiently high to prevent absorption of harmful amounts of moisture and it is recommended that the storage temperature should never exceed 175°F. (80°C.).

The results obtained in these studies did not indicate any significant difference between the lime- and titania-type coatings, either in moisture-absorption or loss of moisture on baking, although the armour-plate welding investigation run in parallel with the tests showed that weld-metal porosity developed at a lower moisture content when using the titania-type than with the lime-type covered electrodes.

Brazing of Titanium to Stainless Steel

W. J. LEWIS, P. S. RIEPPEL and C. P. VOLDRICH: 'A Preliminary Report on the Brazing of Titanium to Titanium and Mild and Stainless Steels.' *Sheet Metal Industries*, 1955, vol. 32, Nov., pp. 833–48.

This extensive report covers work carried out (in 1951–52) at the Battelle Memorial Institute, on behalf of Wright Air Development Center.

Brazed joints were made between titanium/titanium, titanium/stainless steel and titanium/mild steel, using a very wide range of commercial brazing alloys, the compositions and liquidus temperatures of which are detailed in the report.

The large amount of experimental data presented indicates that, in general, furnace-brazed specimens showed higher strengths and more consistent behaviour than specimens torch-brazed with the same alloys. In furnace brazing, pure silver, an 85–15 silver-manganese alloy, and an alloy containing silver 45, copper 15, zinc 16, cadmium 24, per cent., produced joints having shear strengths averaging 13,000 p.s.i. (5·3 tons per sq. in.). The only joints which showed ductility were those made in the furnace, using pure silver or the 85–15 silver-manganese alloy.

Preliminary tests with induction, resistance and shielded carbon-arc brazing showed that higher strengths could be thus obtained, due to the shorter brazing cycles involved, which resulted in less dilution of the brazing alloy and less formation of intermetallic compounds.

None of the experimental fluxes tested gave results so good as those obtained with a flux already available commercially.

A.W.S.-A.S.T.M. Specifications for Stainless-Steel Welding Electrodes

AMER. WELDING SOC.: 'Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Covered Welding Electrodes.' Revised edn., published by *Amer. Welding Soc.*, 1955.

The new edition differs from the earlier one primarily in that eight new classifications have been added to the ten previously included. The new specifications cover extra-low-carbon modifications of Types 308 (carbon 0·08 max., chromium 19–21, nickel 10–12, per cent.), and 316 (carbon 0·10 max., chromium 16–18, nickel 10–14, molybdenum 2–3, per cent.); niobium- and molybdenum-modifications of Type 309 (carbon 0·20 max., chromium 22–24, nickel 12–15, per cent.), and of Type 310 (carbon 0·25 max., chromium 24–26, nickel 19–22, per cent.); Type 312 (29–12 chromium-nickel steel), and Type 318 (niobium-stabilized molybdenum-containing chromium-nickel steel of Type 316. Some simplification with regard to 'usability' designation has also been effected in the revised edition.

A companion volume, entitled 'Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes' contains corresponding classifications for use with atomic-hydrogen, inert-gas metal-arc, and submerged-arc welding.

Brazing Materials and Technique: A.W.S. Handbook

See abstract on p. 206.

Nickel-base Brazing Alloys

SOC. AUTOMOTIVE ENGINEERS: 'Brazing Alloys.' *A.M.S. Specification* 4777, Aug. 15, 1955.

The specification covers material for joining non-ferrous and corrosion- and heat-resistant alloys in applications in which low flow point of the alloy and joints resistant to oxidation at high temperatures are essential. The alloy is suitable also for use

as a corrosion- and oxidation-resistant coating. Limits of composition are as follows: carbon 0·50 max., silicon 3·0–5·0, chromium 6·0–8·0, nickel+cobalt 78·0–86·0 (cobalt, if determined, 1·0 max.), iron 2·0–4·0, boron 2·5–3·5, per cent. The material may be supplied in powder, wire or strip form.

A.M.S. Specification 4778, Aug. 15, 1955.

Another alloy for high-temperature brazing contains carbon 0·50 max., silicon 3·0–5·0, nickel+cobalt 89·0–95·0 (cobalt, if determined, 1·0 max.), boron 1·8–3·5, per cent. This material also can be used in powder, wire, or strip form.

High-Alloy Casting Materials: A.M.S. Specifications

Two new specifications for high-alloy casting materials have recently been issued by the SOCIETY OF AUTOMOTIVE ENGINEERS: their scope is indicated below.

'Alloy Castings, Precision Investment, Corrosion- and Heat-Resistant.' *A.M.S. Specification* 5390, Aug. 15, 1955.

The specification relates to composition, tensile properties, hardness and bend properties, of precision-investment-cast material of the following composition: carbon 0·20 max., silicon 1·00 max., manganese 1·00 max., phosphorus 0·040 max., sulphur 0·030 max., chromium 20·50–23·00, cobalt 0·50–2·50, molybdenum 8·00–10·00, tungsten 0·20–1·00, iron 17·00–20·00, per cent., nickel remainder.

The material is intended primarily for parts such as turbine shroud segments and vanes, which must show good oxidation-resistance up to 2200°F. (1205°C.) and relatively high strength above 1500°F. (815°C.).

'Steel Castings, Sand, Corrosion-Resistant.' *A.M.S. Specification* 5398, Aug. 15, 1955.

This schedule covers composition and properties of precipitation-hardenable steel suitable for use in small parts such as aircraft accessory components in which corrosion-resistance and strength up to 600°F. (315°C.) is required, combined with minimum distortion during fabrication. The composition limits are carbon 0·07 max., silicon 1·0 max., manganese 1·0 max., phosphorus 0·04 max., sulphur 0·04 max., chromium 15·5–17·5, nickel 3·0–5·0, niobium+tantalum 0·45 max., copper 3·0–5·0, nitrogen 0·05 max., per cent., iron remainder.

Hardness, in the as-cast and the precipitation-hardened conditions, is laid down, method of tensile test is specified, and tensile requirements, in the hardened state, are detailed.

Stainless-Steel Tubing: A.M.S. Specifications

Details are given below of two new specifications for austenitic nickel-chromium steel tubing, issued by the SOCIETY OF AUTOMOTIVE ENGINEERS: 'Steel Tubing, Corrosion- and Heat-Resistant (Hydraulic).' *A.M.S. Specification* 5556, Aug. 15, 1955.

The specification relates to seamless or welded-and-drawn tubing of Nb+Ta-stabilized 18–11 chromium nickel steel tubing conforming to S.A.E. Specification 30347. The material is intended primarily for welded parts, and is suitable for assemblies in which oxidation-resistance up to about 1500°F. (815°C.) is called for. It is indicated that the tubing is useful at that temperature only when stresses are low.

The composition limits laid down are as follows:—carbon 0·08 max., silicon 0·50–1·00, manganese 2·00 max., phosphorus 0·040 max., sulphur 0·030 max., chromium 17·00–19·00, nickel 9·00–12·00, niobium+tantalum 10×C—1·10, copper 0·50 max., molybdenum 0·50 max., per cent., iron remainder. The material may be supplied in the solution heat-treated and descaled condition, or otherwise if ordered, the tubing having been produced by the seamless or by the welded-and-drawn process. Specification requirements include tensile properties, a flarability test, microetching for detection of intergranular carbide precipitation, a pressure test, the standard A.S.T.M. boiling nitric-acid test, determination of grain size, and exposure to the standard copper-sulphate embrittlement test.

'Steel Tubing, Corrosion- and Heat-Resistant (Hydraulic).' *A.M.S Specification* 5557, Aug. 15, 1955.

The compositional limits of this specification vary somewhat from those of A.M.S. 5556, and titanium is employed as stabilizer. The range is carbon 0·08 max., silicon 0·40–1·00, manganese 2·00 max., phosphorus 0·040 max., sulphur 0·030 max., chromium 17·00–20·00, nickel 8·00–13·00, titanium 6×C—0·70, molybdenum 0·50 max., copper 0·50 max., per cent., iron remainder. The types of test required are similar to those required in the previous specification.

High-Expansion Nickel-Manganese Steel

SOC. AUTOMOTIVE ENGINEERS: 'Steel, High-Expansion.' *A.M.S. Specification* 5625, Aug. 15, 1955.

Steel intended primarily for bolts and screws required to have a coefficient of expansion approaching that of aluminium alloys is of the following composition:—carbon 0·55–0·65, silicon 1·00 max., manganese 5·00–6·00, sulphur 0·030 max., phosphorus 0·040 max., nickel 8·50–10·50, per cent.

Tensile and hardness requirements are laid down, and it is specified that the material shall be capable of showing a coefficient of thermal expansion not lower than $11{\cdot}5\times10^{-6}$ per °F. over the temperature range 72°–600°F.

A.S.M. Metals Handbook: Stainless-Steel Section

'The Selection and Application of Stainless Steel in the Chemical Process Industries.' *Metal Progress*, 1955, vol. 68, Aug. 15, pp. 37–49.

The intrinsic character of the corrosion-resisting steels is reviewed, and conditions in which intergranular corrosion, stress-corrosion cracking, pitting, or localized corrosion can be induced in such materials is indicated. The contribution which design and fabrication methods can make towards producing or avoiding corrosion attack is discussed.

In connexion with corrosion testing, emphasis is

laid on close reproduction of working conditions and, where possible, of actual service tests. A chart, based on a large number of laboratory investigations and on service records, shows the behaviour of chromium, chromium-nickel, and chromium-nickel-molybdenum-copper steels in contact with a wide range of commonly used corrodents. All the data relate to conditions in which carbon steel has been proved to give inadequate resistance.

Concise notes are given on serviceability of the respective types of steel in contact with acetic acid, ammonium sulphate+free sulphuric acid, bromoform, chlorinated solvents, chlorosulphonic acid, epichlorohydrin, fatty acids, hydrochloric acid, hydrocyanic acid, lactic acid, monoethanolamine, nitric acid, phosphoric acid, silver nitrate, sodium sulphide, stannic chloride, stannous fluoride, sulphation and sulphonation products, sulphuric acid, sulphurous acid and sulphur dioxide, fine and pharmaceutical chemicals.

The final section of the report reviews the uses of the stainless steels in the pulp and paper industry, and in various branches of the food industry.

Nickel-containing Materials in Chemical Engineering: Review

Part II of the September issue of Industrial and Engineering Chemistry contains the Ninth Annual Review of Materials of Construction for Chemical Engineering. The scope of the survey is shown below, with notes on sections which are of interest in relation to nickel-containing materials.

H. O. TEEPLE: 'Nickel, including High-Nickel Alloys;' pp. 1990–2006.

This review, supported by a classified *bibliography* of 266 items, opens with brief notes on nickel resources, and developments in methods of extraction. The major portion of the survey is concerned with literature relating to physical and mechanical properties, composition, fabrication (including welding and brazing, mechanical forming, and machining), and applications. Reference is also made to plating (in the Properties and Composition section). The last section of the review is devoted to consideration of the use of nickel and high-nickel alloys in the chemical and process industries.

W. A. LUCE: 'Stainless Steels, including other Ferrous Alloys', pp. 2023-35.

An introductory section contains notes on the supply position with regard to metals which are required for various types of stainless steel. Recent literature is then reviewed in sections covering, respectively, corrosion and stress-corrosion, mechanical properties and structure of the stainless steels, high-temperature properties and uses of austenitic and other stainless steels, welding technique and equipment. The more general items of literature are also reviewed and further sections deal with manufacture and fabrication, surface treatment, heat-treatment, powder-metallurgy production and other aspects.

The final section of the review is concerned with miscellaneous iron-base alloys, dealing with high-silicon irons, iron-nickel alloys, nickel-containing cast-irons and austenitic manganese steel.

The classified *bibliography* comprises some 200 items.

Aluminium alloys, pp. 1946–52; carbon and graphite, pp. 1953–5; ceramics, pp. 1956–62; elastomers, pp. 1963–72; fibres, pp. 1973–81; iron and mild steels, including low-alloy steels, pp. 1982–5; lead, pp. 1986–9; paints, pp. 2007–10; plastics, pp. 2011–19; hard rubber, pp. 2020–2; tin and its alloys, pp.2036–40; titanium, pp. 2041–3 see also tabular data, pp. 2052–3 less common metals, pp. 2044–50 (zirconium, hafnium, molybdenum, tantalum, niobium and rhenium: see also tabular data on zirconium, pp. 2054–63).

New Types of Precipitation-Hardening Austenitic Steel Castings

'New Precipitation-Hardenable Stainless Alloys.' *Materials and Methods*, 1955, vol. 42, Sept., p. 144.

Four new grades of stainless-steel casting are announced by Cooper Alloy Corporation, Hillside, New Jersey. Limits of composition are shown on p. 237.

Steel 55A is described as having high strength and hardness, with fair ductility, and as being suitable for use in applications in which erosion- and abrasion-resistance are critical and for stressed parts used in corrosive conditions.

Steel 55B is a ductile material of medium hardness, to provide shock-resistance and high strength in corrosive conditions.

Steel 55C is characterized by high hardness and low ductility, and is recommended for non-stressed corrosion-resisting parts.

Steel P.H.20 is claimed to show good resistance to galling, with superior corrosion-resistance.

Mechanical properties typical of all the materials are given in the original.

Valves for Handling Corrosive Fluids: Use of Nickel-base Alloys

E. G. HOLMBERG: 'Valves for Corrosive Fluids.' *Corrosion*, 1955, vol. 11, Sept., pp. 406t–14t.

The aim of this article is to present information which will be of practical value in selecting materials and design for valves operating in contact with corrosive liquids of various types. The major importance of plant tests, combined with laboratory investigation, is emphasized, and attention is drawn to the influence of minor changes in composition of corrosion-resisting materials, as affecting their behaviour under specific conditions. In this connexion typical case histories of valve failure from corrosion are recorded.

In considering the aspect of composition, specific reference is made to service tests on nickel-chromium-iron alloys and austenitic nickel-chromium steels of simple and complex types: the value of molybdenum additions in enhancing resistance to attack by many corrosives is demonstrated.

A large part of the paper is concerned with design of valves and their component parts; recommendations are made with regard to designs suitable for

Steel	C %	Si %	Mn %	Cr %	Ni %	Mo %	Cu %	Nb %	N %
P.H.55A	0·08 max.	3·0-3·75	1·0 max.	19·5-20·5	8·5-9·5	3·75-4·25	—	—	—
P.H.55B	0·08 max.	1·25-1·75	1·0 max.	19·5-20·5	8·5-9·5	4·75-5·25	3·25-3·75	—	—
P.H.55C	0·08 max.	3·25-3·75	1·0 max.	19·5-20·5	8·5-9·5	3·75-4·24	2·75-3·25	—	—
P.H.20	0·07 max.	1·5 max.	2·5 max.	19-22	27-30	2-4	3-4	1·0 max.	0·10-0·15

individual types of service. The authors refer to existing U.S. standards for chemical valves and to additional standards which are likely to be drawn up for valves required to handle corrosive liquids at pressures above 150 p.s.i.

Cavitation Testing of Metals and Alloys

M. S. PLESSET and A. T. ELLIS: 'On the Mechanism of Cavitation Damage.'
Trans. Amer. Soc. Mechanical Engineers, 1955, vol. 77, Oct., pp. 1055-64; disc., p. 1064.

It has long been recognized that the cavitation produced by variations of pressure at relatively high frequencies will produce damage more rapidly than cavitation occurring under ordinary flow conditions. Laboratory test methods have been based on high-frequency acceleration of the test specimen relative to the liquid medium, and in most cases the acceleration has been obtained by application of the magnetostrictive effect in a nickel rod, to the end of which the test specimen is applied.

The present authors describe a new method of test, in which no mechanical accelerations are applied to the specimen. Alternating pressures are generated in the water over the specimen, by exciting a resonance in the 'water cavity'. X-ray analysis and/or photomicrographic examination of stainless steel, zinc, nickel, brass, titanium and other materials shows that plastic deformation occurs in the specimens, so that the ultimate damage arises from cold work, leading to fatigue and failure.

Using the apparatus described, the following materials were tested for resistance to cavitation: the list is given in *order of ascending hardness*:—

Aluminium (soft), titanium (annealed), nickel, molybdenum, 70–30 brass, 18–8 chromium-nickel steel, titanium alloy, low-chromium steel, tungsten, titanium-manganese alloy, Colmonoy (nickel-chromium-boron alloy), titanium-chromium-iron alloy, Stellite (cobalt 55, chromium 33, tungsten 6, per cent.), Pyrex, fused quartz.

The results show that, in general, hard materials of high tensile strength are the most resistant to damage: in these tests titanium-chromium-iron alloy and tungsten gave the best behaviour.

Cavitation tests in liquid toluene and in a helium atmosphere indicate that, at most, chemical effects are of only secondary significance.

Determination of Galvanic-Couple Corrosion in Atmospheric Conditions

K. G. COMPTON, A. MENDIZZA and W. W. BRADLEY: 'Atmospheric Galvanic-Couple Corrosion.'
Corrosion, 1955, vol. 11, Sept., pp. 383t-92t.

Galvanic-couple corrosion has been extensively studied in sea water and in connexion with chemical-process equipment, but relatively few quantitative data applicable to atmospheric corrosion have been published: see, however, reports by the American Society for Testing Materials (*Proceedings*, 1935, vol. 35, p. 167: 1939, vol. 39, p. 247; 1948, vol. 48, p. 167).

In the work reported in this paper the probable behaviour of couples under atmospheric exposure was assessed by measuring galvanic-couple corrosion currents and electrode potentials in conditions simulating atmospheric conditions, and by weight-loss data from couples subjected to representative atmospheres. The test equipment and technique are described and illustrated. The electrode materials were used in the form of thin sheet, separated by filter paper saturated with the selected electrolytes: the test specimens included aluminium; magnesium alloy; stainless chromium and chromium-nickel steels; nickel-copper alloy (Monel); brass; copper; electrodeposited cadmium, zinc, tin, nickel, chromium and lead coatings on steel; silver, and low-carbon steel. It is considered that the measurements of corrosion currents provide a rapid means for determination of the probable relative corrosion behaviour of couples. Differences between 'sheltered' and 'unsheltered' conditions are discussed.

Influence of Solid Surface Films on Friction- and Wear-Resistance

See abstract on p. 205.

Strength of Materials: Textbook

See abstract on p. 220.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

SUBJECT INDEX TO VOLUME 28

The Index comprises a consolidated list of titles of abstracts, compiled from the sectional contents lists of the individual issues.

Within the Sections normally used (**GENERAL, NICKEL, ELECTRODEPOSITION,** etc.), the items are broadly classified in appropriate sub-sections, within which the items are, in most cases, entered in the order of their appearance in the Bulletin. The only exceptions to such order are (1) the grouping of the page numbers of serial items, and of items of very closely related subject and, (2) the alphabetical order used in the **'GENERAL'** Section.

An additional feature is introduced this year, in the form of a list of **Trade-Named Materials and Processes** referred to in the Nickel Bulletin for 1955.

Page

GENERAL

(See also **General** and **Testing** Sub-Sections of main subjects.)

The items which are listed in the Section have been entered also in other appropriate sections of the Contents List.

Aircraft Design and Materials 223
Brazing Manual 206
Charpy Impact Test: Reproducibility 143
Chemical and Electrochemical Polishing of Metals and Alloys 58, 104, 152, 164
Cladding of Metals by Vacuum Brazing 175
Diffusion Tests 30, 143, 144, 206, 214, 228
Failures in Service: Typical Case Histories 26
Identification Tests for Metals and Alloys 206
Metals Reference Books 174, 205, 220, 235
Nuclear Power Plant: Materials for 27, 59, 60, 164, 176
Radioactive Test Methods 144, 211, 214, 228
Resistance Sintering of Metal Powders 58
Sintering in Non-Ferrous Metals: Mechanism of 206
Surface Films on Metals: Influence on Wear and Friction 205
Testing of Sintered Metal Components 99
Thermal Conductivity of Metals 26, 99, 175

NICKEL

Analysis and Determination (see also **ELECTRODEPOSITION, Analysis of Solutions**)

Determination of Traces of Nickel on Catalysts 27
Spectrophotometric Determination of Nickel as the Dimethylglyoxime Complex 27
Determination of Nickel in Presence of Cobalt and Iron 27, 209
" " Magnesium in Nickel 27
Photometric Determination of Nickel in Steels and Alloys 61, 84, 143, 181
Analysis of Thin Films of Nickel 84
Non-Ferrous Metallurgical Analysis 109
Determination of Nickel in Low- and High-Alloy Steels 148, 181
Determination of Nickel in Tungsten Powder 181
" " Malt Beverages 181
Thioacetamide Separation of Nickel and Cobalt 209
Determination of Lead in Nickel 210
" " " Nickel in Titanium Alloys 210
" " " " Petroleum 210
" " " " Aluminium Alloys 215

Composition, Properties and Structure

Precipitation-Hardenable Nickel 2
Composition and Properties: Data Sheet on Nickel 3
Thermal Conductivity of Nickel 26, 99, 175
Corrosion by Molten Sodium Hydroxide 27, 59, 60, 164, 176
Diffusion between Nickel and other Metals 30, 60, 143, 206, 214
Creep of High-Purity Nickel 42
Vapour Pressure of Nickel 43
Specific Heat " " 58
Polarization of Nickel in Sodium-Chloride Solutions 59
Catalytic Activity of Nickel: *see* **Uses**
Nickel Films Deposited by Thermal or Chemical Means (see also **ELECTRODEPOSITION** Section) 59, 84
Diffusion of Gases through Nickel 60, 101
Resistance to Dry Corrosion at Elevated Temperatures 70, 117, 161, 196
Resistance of Nickel to Fluorine and Hydrofluoric Acid 78, 79
Solubility of Oxygen in Molten Nickel 83
Magnetostriction/Temperature Relationships 100
Nickel-base Materials in Electronic Valves 100, 101, 208
Oxidation of Nickel 102, 117, 145, 179, 205
Self Diffusion of Nickel 144
Resistance to Water at Elevated Temperature 154, 231
" " Vanadium Pentoxide 161
Corrosion by Chlorine-Dioxide Solutions 166
Metals Reference Book 174
Effect of Sulphur in Nickel 178
Pure Nickel Produced by Electrolysis of Chloride Solutions 183
Corrosion by Nitric Oxide 196
Surface Films: Effect on Wear and Friction 205
Stored Energy and Lattice Defects in Cold-Worked Nickel 207
Gyromagnetic Ratio of Nickel 207
Cavitation-Resistance of Nickel 237

Nickel-Clad Steel: *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Clad, Faced and Lined Materials**

Occurrence, Extraction and Refining

Nickel Industry in 1953 and 1954: O.E.E.C. Report 42
Ammonia Pressure-Leaching Process for Extraction of Nickel 83, 177
Nickel in Iron and Steel: Textbook 88
Nickel-Copper Ores in the Sudbury Region, Ontario 143, 176
Sherritt Gordon Nickel Mines: Historical Survey 176
Nickel-containing Ores of Cuba 177, 207

Page

Powder Production, Properties and Uses (for Nickel and Nickel-Alloy Binders in Cermets, *see* **HEAT- AND CORROSION-RESISTING MATERIALS, Powder Production**)

Sintered–Powder Plates in Alkaline Batteries 2, 60, 143
Testing of Sintered Powder Components 99
Powder–Produced Nickel Cathodes 208

Production and Processing (see also **Occurrence, Extraction and Refining,** and **Welding**)

Precipitation–Hardening of Nickel 2
Cold Drawing of Nickel Tubes 3
Nickel Industry in 1953 and 1954 42
Chemical and Electrochemical Polishing of Nickel 58
Nickel Films Deposited by Thermal Processes or Chemical Precipitation 59, 84
Purification of Nickel for Radiation Experiments 99

Specifications and Testing

Nickel Welding Electrodes and Brazing Materials A.W.S./A.S.T.M. Specifications 31
Creep Testing of Nickel 42
Thermal–Conductivity Test Methods 99
Testing of Sintered Powder Components 99
Metals Reference Book 174

Uses (see also **Nickel Salts and Compounds,** and **Powder Production and Uses**)

Nickel in Nuclear Engineering Plant: Sodium–Hydroxide Attack, etc. 27, 59, 60, 164, 176
Nickel–Alkaline Batteries 28, 143
Nickel–Molybdenum Thermocouple 42
End–Uses of Nickel: Control in 1953–54 42
Nickel–containing Catalysts 59, 101, 102, 179, 180, 207, 208
Nickel in Gas Diffusers 60, 101
Nickel in Electronic Valves 100, 101, 208
Ultrasonic Equipment for Protection of Ships' Hulls from Barnacles 181

Welding, Brazing and Soldering, also **Gas- and Arc-Cutting**

Nickel Welding Electrodes: A.W.S./A.S.T.M. Specifications 31
Inert–Gas Metal–Arc Cutting of Nickel 108
* Joining of Nickel and Nickel Alloys: Data Sheet 172–3
Brazing Manual 206
Argon–Arc Welding of Nickel 209
Inert–Gas–Shielded Arc Welding of Nickel 231

Nickel Salts and Compounds (see also **ELECTRO-DEPOSITION**)

Reaction between Nickel and Molten Sodium Hydroxide 27, 60, 164, 176
Nickel Chelates 28
Nickel Carbonyl: Heat Capacity and Thermodynamics of Formation 43, 179, 210
Tungsten–Nickel Sulphide Catalysts 101, 102
Nickel Oxide–Silica–Alumina Catalysts 102
Oxide Films Formed on Nickel 102, 179
Properties of Nickel Oxide 102, 210
Nickel–Carbonyl/Phosphorus Compounds 102
Nickel Trifluoroacetate in Plating Solutions 105
Metals Reference Book 174
Nickel–Sulphur Reactions: Formation of Nickel Sulphide 178
Adsorption of Gases on Nickel Oxides 179
Preparation of Nickel Catalysts from Mixed Oxalates 179
Calcium–Nickel Phosphate Catalysts in Butadiene Manufacture 180

* *Leading Article*

Page

Influence of Nickel on Plant Culture 181
Adsorption of Chlorine Trifluoride on Nickel Fluoride 211
Nickel Difluoride: Properties 211
Nickel Compounds in Detection of Formaldehyde 211

ELECTRODEPOSITION AND OTHER COATING METHODS

(See also **HEAT- AND CORROSION-RESISTING MATERIALS, Clad Materials**)

Analysis of Solutions and Effluents

Estimation of Boric Acid in Nickel–Plating Baths 2
Analysis of Effluents from Plating Baths 86
Polarographic Analysis of Nickel–Plating Solution 107

Electrodeposition of Alloys

Tin–Nickel Plating 18, 214
Electrodeposition of Alloys: Reviews 28, 61, 105
" " Iron–Zinc Alloys 103
" " Tungsten–Cobalt Alloys 103
Corrosion of Tin–Cadmium Coatings 103
Electrodeposition of Molybdenum–Nickel Alloys 184
Nickel–Cadmium Diffused Coatings 226

Electrodeposition of Nickel: Properties and Uses of Electrodeposited Nickel

Electrodeposition of Nickel from Sulphamate Baths 28
Nickel Plating of Wire 43
Electrodeposition of Nickel from Fluoborate Solutions 43, 183
Electrodeposition by Dalic Brush–Plating Process 44
Hardness and Buffing Quality of Electrodeposited Coatings 44
Electrodeposited Nickel in Nuclear Power Plant 59
Electroplating in 1954: Review 61
Nickel–Chromium Plating of Magnesium–base Materials 61, 106
Hardness and Wear–Resistance of Electrodeposited Metal Coatings 62
Influence of Condition of Basis Metal in Electroplating 85, 105
Inhibited Acids in Nickel–Plating Baths 85
Plating of Bumper Guards: Use of Nickel Strike 85
Structure, Properties, and Uses of Electrodeposited Coatings 104, 105, 107
Electrodeposition of Nickel with Perfluorinated Acids 105
Porosity of Electrodeposited Nickel 156
Production of High–Purity Nickel by Electrolysis of a Chloride Solution 183
Bright Nickel Plating: Review 212
Metallic (and Non–Metallic) Coatings: Textbook 213
Nickel+Cadmium Diffused Coatings for Aircraft Use 226
Atmospheric Galvanic-Couple Corrosion Tests on Coatings 237

General

Metallurgical Hardness and Buffing Quality of Electrodeposited Coatings 44
Electroplating in 1954: Review 61
Influence of Condition of Basis Metal in Electroplating 85, 105
Institute of Metal Finishing: Conference Papers 102
Chromium Plating: Effect on Fatique Properties of Steel 102
Cracking in Chromium Deposits 103
Plating of Screw Threads 104
Electroforming in Electronic Engineering 104

Page

Paint Coatings: Blistering, Testing, etc. 104
Technical Training for Metal–Finishing Industries 104
Engineering Applications of Electrodeposited Coatings 105
Electrodeposition of Chromium, Cobalt (and Nickel), using Perfluorinated Acids 105
Cleaning of Metals Prior to Electroplating 183, 212
Activation of Surfaces for Electroless Plating 184
A.S.M. Metals Handbook: Selection of Metal Coatings 205
Anodic Etching before Plating 212
Protective Coatings: Textbook 213

Other Coating Methods

Electroless Plating: Kanigen and Related Processes 28, 29, 44, 45, 86, 107, 144, 156, 184, 213
Electrodeposition of Metals by Dalic Brush–Plating Process 44
Literature of 1954: Review 61
Paint Coatings: Blistering, etc. 104
Protective Coatings: Textbook 213
Electrophoretic Deposition of Nickel 214
Production of Ultra–Thin Layers of Nickel–Iron Alloys by Vacuum Evaporation 216 (see also 65)
Calorizing, Aluminizing, etc., for High–Temperature Service 225
Diffused Nickel–Cadmium Coatings 226

Specifications and Testing

Electroplating in 1954: Review 61
Salt–Spray Test: Acetic–Acid Modification 61, 140
Hardness and Wear–Resistance Tests 62
Analysis of Stress in Deposits 103
Specification for Heavy Nickel Plating 107
Thickness Testing of Electrodeposited Coatings 107
Porosity Testing „ „ „ „ 156
Corrosion Testing „ „ „ „ 182, 237

NON-FERROUS ALLOYS

Analysis (see also **NICKEL, Analysis and Determination**)

Determination of Zinc in Coinage Alloys 4
Non-Ferrous Metallurgical Analysis: Review 109
Photometric Determination of Nickel in Copper–base Alloys 143
Analysis of Titanium Alloys 210
„ „ Light Metals and Alloys 215

Cladding with Non-Ferrous Metals and Alloys: *see* **HEAT- AND CORROSION-RESISTING MATERIALS, Clad, Faced and Lined Materials**

Composition, Constitution and Structure

Age-Hardenable Alloys: Reference Data 2
Monel, K Monel and Inconel: Data Sheets 3
Transformations in Nickel–Aluminium Bronzes 3, 87, 126
Cobalt–Nickel–Manganese Alloys 3
Nickel–Aluminium Alloys: Constitution, etc. 7
Nickel in Germanium 30, 157
Nickel–Chromium–NiAl System 45
Nickel–Bismuth Alloys 45
Constitutional Studies on Alloy Systems: Bibliography 63
Chromium–Rich Chromium–Nickel Alloys 86
Nickel in Ternary Alloys of Uranium 87
Titanium–Nickel–Oxygen System 87
Nickel–base Alloys used in Electronic Valves 100, 101
Magnetic Properties of Sigma–Phase Alloys 107
Hume–Rothery Phases in Nickel–Copper–Tin Alloys 108

Page

Nickel–Titanium Alloys: Equilibrium Diagram 126
Indium Alloys: Review 145
Amalgams as an aid in the Study of Nickel–Alloy Systems 156
Elastic Modulus of Aluminium Alloys: Influence of Composition 157
Magnetic Structure of Nickel–Manganese Alloys 157
Metals Reference Book 174
Gold–Nickel Alloys: Heat Capacities: Self Diffusion 185, 215
Titanium–Nickel Alloys 185
Nickel–Chromium–Carbon Alloys 214

General

Age-Hardenable Alloys: Reference Data 2
Failures in Service: Typical Examples 26
Fabrication of Nickel Alloys: Commercial Practice 45, 62, 160
Control of Quality in Production of Wrought Non-Ferrous Alloys: Symposium 62
Metals Reference Book 174
Strength of Materials: Textbook 220

Plating: *see* **ELECTRODEPOSITION**

Powder Production and Use (for Nickel–Alloy Binders in Cermets, *see* **HEAT- AND CORROSION-RESISTING MATERIALS, Powder Production and Use**)

Testing of Sintered Metal Components 99
Sintering of Mixed Metal Powders 157

Production and Processing (see also **Welding**)

Precipitation Hardening of Alloys: Review 2
Cold–Drawing of Nickel–Alloy Tubes 3
Nickel–containing Coinage Alloys 4
Fabrication of Nickel Alloys: Commercial Practice 45, 62, 160
Chemical and Electrolytic Polishing of Alloys 58, 152
Control of Quality in Production of Wrought Non–Ferrous Materials: Symposium 62
Electrolytic Oxidation of Copper and Copper Alloys 104
Magneto–Thermal Treatment of Nickel-Cobalt Alloys 108

Properties (see also **Specifications**)

Precipitation–Hardening Alloys: Review 2
Monel, K Monel, Inconel: Data Sheets 3
Non-Ferrous Permanent–Magnet Alloys 4, 46
Nickel–Aluminium Alloys: High–Temperature Properties 7
Resistance of Nickel Alloys to Phosphoric Acid 19, 230
„ „ „ Corrosion in Petroleum Industry 20
Resistance of Nickel–Molybdenum Alloys to Iodine 20
Thermal Conductivity of Non–Ferrous Alloys 26, 99, 175
Porosity in Nickel–Bronze Casting 31
Corrosion–Resistance of Cupro–Nickel and Other Copper Alloys 38, 155
Magnetostriction in Nickel–Copper Alloys 45
Super–Conducting Nickel–Bismuth Alloys 45
Resistance of Nickel Alloys to Hydrofluoric Acid and Fluorine 54, 79, 95, 108
Polarization of Nickel–Copper Alloys in Sodium Chloride Solutions 59
Resistance of Non–Ferrous Alloys to Dry Corrosion at Elevated Temperatures 70, 117, 196
Enthalpy and Specific Heat of Monel 91
Mechanical Properties of Monel: Effect of Temperature 92
Monel and Cupro–Nickel for Pressure Piping: A.S.A. Tests 92

Page

Properties of Nickel Alloys used in Electronic Valves 100, 101
Magnetic Properties of Sigma–Phase Alloys 107
Resistance of Monel to Marine Conditions 120, 167
Creep in Nickel–Aluminium Bronze Alloys 126
Diffusion of Other Elements in Nickel–Titanium Alloy 143
Cobalt–Nickel Alloys: Oxidation Characteristics 145
: Young's Modulus 215
Cast Copper Alloys: Effect of Nickel on High-Temperature Properties 146
Resistance of Nickel Alloys to Water at Elevated Temperatures 154, 196
Nickel–Manganese Alloys: Structure and Magnetic Properties 157
Corrosion of Non-Ferrous Alloys by Chlorine–Dioxide Bleaches 166
Metals Reference Book 174
Gold–Nickel Alloys 185, 215
Corrosion by Nitric Oxide 196
Ferromagnetic Hall Coefficient of Nickel Alloys 215
Titanium Alloys containing Nickel 215
Strength of Materials: Textbook 220
Atmospheric Galvanic–Couple Corrosion Tests 237

Specifications and Testing

Determination of Thermal Conductivity 26, 99
Shafts in Non-Ferrous Alloys: Specifications 31
Nickel and Nickel–Alloy Welding Electrodes: A.W.S./A.S.T.M. Specification 31
Control of Quality in Production of Wrought Non–Ferrous Materials: Symposium 62
Testing of Materials for Pressure Piping 92
Testing of Sintered Powder Components 99
Nickel Alloys used in Electronic Valves: Specifications for 100, 101
Metals Reference Book 174
Cupro-Nickel Alloys for Pressure Vessels: A.S.M.E. Code 192

Uses (see also **Powder Production and Use**)

Nickel–Aluminium Bronze Propellers 3
Nickel–containing Coinage Alloys 4
Non–Ferrous Permanent–Magnet Alloys 4, 46
Nickel Alloys for Phosphoric–Acid Plant 19, 230
„ „ in the Petroleum Industry 20
Shafts in Non-Ferrous Alloys 31
Nickel–containing Brazing Alloys 34, 50, 74, 75, 97, 234, 235
Nickel Alloys for Handling Sulphuric Acid and Sludges 37
Nickel Alloys in Thermocouples 42, 174
„ „ for Handling Fluorine and Hydrofluoric Acid 54, 79, 95, 108
Overlays for Ferrous Materials 77, 219
Monel and Cupro–Nickel for Pressure Piping 92
Nickel–base Alloys in Electronic Valves 100, 101
Nickel Silver, Monel and Hastelloy D in Chemical–Feed Equipment 120
Monel for Protection of Steel in Marine Installations 120, 167
Monel Stays in Locomotives 156

Welding, Brazing and Soldering, also **Gas- and Arc-Cutting**

Nickel and Nickel–Alloy Welding Electrodes: A.W.S./A.S.T.M. Specification 31
Nickel–base Alloys for Brazing Titanium 34
„ „ „ „ Molybdenum 75

Page

Overlaying of Steel and Cast Iron with Nickel Alloys 77, 219
Inert–Gas Metal–Arc Cutting of Nickel Alloys 108
Joining of Nickel Alloys: Data Sheet 172–3
Metals Reference Book 174
Welding of Copper and Copper–base Alloys 185
Brazing Manual 206
Inert–Gas–Shielded Arc Welding of Alloys 231
Brazing of Titanium to Steel 234

NICKEL-IRON ALLOYS

Composition, Constitution, Structure and Properties, *excluding* **Magnetic Properties,** *q.v.*

Precipitation-Hardening Nickel–Iron Alloys 2
Constitutional Studies on Alloy Systems: Bibliography 63
Transformations and Segregation Phenomena in Nickel–Iron Alloys 64, 109, 157
Carbon–containing Nickel–Iron Alloys: Phase Diagram 64
Solubility of Oxygen in Molten Iron–Nickel Alloys 83
Calibration of Nickel–Iron Length Standards 87
Diffusion of Hydrogen through Nickel–Iron Alloy 94
Amalgams as an Aid to Study of Alloy Systems 156
Metals Reference Book 174
Sulphur Activity in Liquid Iron–Nickel Alloys 186
Self Diffusion of Iron in Nickel–Iron Alloys containing Carbon 186
Texture/Thickness Relationships in Nickel-Iron Alloys 186
Oxidation of Nickel–Iron Alloys 187
Bimetals: Nickel Alloys used in 216

Magnetic Properties and Uses arising therefrom (see also **Powder Production and Use**)

Permanent–Magnet Materials: Textbooks 4, 65
: Recent Developments 4
Flux Resetting Characteristics of Magnetic Nickel Alloys 31
Casting of Permanent Magnets 45
Permanent–Magnet Materials having High Coercive Force 46
Properties of Nickel–containing 'Ferrites' 47, 216, 217
Magnetic Properties of Evaporated Nickel–Iron Alloy Films 65, 216
Magnetostriction in Cobalt–Nickel–Iron Alloys 65
Fabrication of High–Permeability Alloys: American Practice 66
Magnetic Investigation of Transformation and Segregation Phenomena in Nickel–Iron Alloys 109
Effect of Low Temperatures on Nickel–containing Magnet Alloys 109
Magnetic Structure of Nickel–Iron Alloys 157
Metals Reference Book 174
Magnetization Reversal in Thin Films of Nickel-Iron Alloy 186
Texture/Thickness Relationships in Magnetic Alloys 186
Grain–Boundary Effects in High–Permeability Alloys 187
Permalloy Tape Cores in Digital Computers 187
Production of Ultra–Thin Films of Magnetic Nickel–Iron Alloys by Evaporation 216

Powder Production and Use

Permanent–Magnet Materials and their Uses: Textbooks 4, 65

Page

Properties of Nickel–containing 'Ferrites' 47, 65, 216, 217
Testing of Sintered Powder Components 99
Sintering of Mixed Powders 157

Specifications and Testing

Permanent–Magnet Materials 4, 65
Calibration of Length Standards 87
Testing of Sintered Powder Components 99
Metals Reference Book 174
Precipitation–Hardening Alloy Strip: Specification 216

CAST IRON

General

Austenitic Cast Irons 66, 117, 158, 159, 188
Overlaying Cast Iron with Non–Ferrous Materials 77,219
Nickel in Iron and Steel: Textbook 88
Elevated–Temperature Properties of Cast Irons (including Oxidation–Resistance) 66, 67, 117, 127, 158, 159, 188, 217
Low–Temperature Properties of Cast Irons 129, 130, 131
Titanium in Iron and Steel: Textbook 131
Alloy Cast Iron for Tappets 158
Thermal–Shock Resistance of Cast Irons 158
Metals Reference Book 174
Ni-Resist: Properties and Applications 188 (see also 159), 217
Brazing of Cast Iron 206
Cast Iron for Elevated–Temperature Use: Specification 217
Strength of Materials: Textbook 220

Spheroidal-Graphite Cast Iron (S.G. Iron)

Thermal Stability 66
Impact Characteristics 66
Austenitic S.G. Irons 66, 110, 217
High–Temperature Properties 67, 110, 127
S.G. Iron for Crankshafts 67
Low–Temperature Properties 129, 130
Thermal–Shock Resistance 158
Annealing of S.G. Iron 188
S.G. Iron for Dies and Tools 219
„ „ in the Petroleum Industry 219

CONSTRUCTIONAL STEELS

Analysis (see also **NICKEL, Analysis and Determination**)

Determination of Tungsten 5
„ „ Molybdenum 32, 112
Chemical Analysis of Steel: German Practice 47
Determination of Aluminium 113
Mercury–Cathode Electrolysis in Analysis of Iron and Steel 113
Spectrochemical Control Analysis in Steelworks 131
Determination of Nickel in Low– and High–Alloy Steels 148, 181

Composition, Constitution, Structure (see also **Specifications**)

Precipitation–Hardening Steels 2
Embrittlement of Tempered Martensite in Low–Carbon Steels 4
Stabilization of the Bainite Reaction 5
Carbon-containing Nickel–Iron Alloys: Phase Diagram 64
Effect of Pouring Conditions on Structure of Ingots 67
Influence of Vanadium on Transformations in Nickel–Chromium Steel 67
Nickel in Iron and Steel: Textbook 88

Page

Temper–Brittleness: Influence of Variables in Composition, etc. 88, 89
Case–Hardening Steels: Transformational Characteristics and Impact Properties 110
Hairline Cracking in Steel: Zirconium as Preventive 110
Titanium in Iron and Steel: Textbook 131
Metals Reference Book 174
Sulphur Reactions in Steel 186
Flake Formation in Steels 189
Rare-Earth Additions to Steels 220
Structural Changes in Low–Alloy Steels during Creep 222, 223

General

Failures in Service: Case Histories 26
Overlaying Steel with Nickel Alloys 77, 219
Nickel in Iron and Steel: Textbook 88
Titanium in Iron and Steel: Textbook 131
Metals Reference Book 174
Steel–Sulphur Reactions 178
A.S.M. Metals Handbook 205
Strength of Materials: Textbook 220
Aircraft Design and Materials: Seminar 223

Plating: *see* **ELECTRODEPOSITION**

Powder Production

Wear–Resisting Steels made from Powders 6

Production and Processing (see also Textbooks referred to in **General** Sub–Section, and **Welding**)

Precipitation Hardening of Steels 2
Embrittlement of Tempered Martensite in Low–Carbon Steels 4
Stabilization of the Bainite Reaction 5
Chemical and Electrochemical Polishing of Steels 58, 104
Effect of Pouring Conditions on Structure of Ingots 67
Temper–Brittleness in Steels: Influence of Treatment 88, 89
Understressing of Steel to Raise the Fatigue Limit 148
Flake Formation in Steels 189
Creep of Chromium–Molybdenum–Vanadium: Influence of Heat–Treatment 192

Properties and Uses (see also **Specifications**)

Precipitation–Hardened Steels 2
Embrittlement of Tempered Martensite in Low–Carbon Steels 4
Nickel–Alloy Steel Flaptracks in Aircraft 5
Poppet Valves, Guides, etc.: Materials used 5
Wear–Resisting Steels made by Powder–Metallurgy 6
Thermal Conductivity of Steels 26, 175
Shafts in Alloy Steels 31
Nickel–Alloy Steels for Machine Tools 47
Low–Alloy Steels used in Power Plants 48, 116, 132, 192
Tough Nickel–Alloy Plate Steel 68
Low–Alloy Steels used in Aircraft Gas Turbines: Reviews 71, 224
Nickel in Iron and Steel: Textbook 88
Temper–Brittleness in Steels 88, 89
Alloy Steels for Pressure Piping 92
Fatigue Properties 102, 111, 148
Case–Hardening Steels: Transformations and Impact Properties 110
Hairline Cracking: Zirconium as Preventive 110
Nickel Additions to Chromium–Molybdenum Cast Steels 116

Page

Creep-Resisting Steels used in Power Plants 116, 132
Brittleness in Metallic Materials: Effect of Low Temperatures 128, 146, 189
Titanium in Iron and Steel: Textbook 131
Charpy Impact Tests on Nickel-Alloy Steel 143
Transition Temperature of Nickel Steel Plate 146
Nickel-Alloy Steel Pinions in Blooming Mill 148
Corrosion-Resistance of Low-Alloy Steels 153
Metals Reference Book 174
Flaky Steel 189
Sub-Zero Properties of Steels 189
Chromium-Molybdenum-Vanadium Steel: High-Temperature Properties 192
Steels containing Rare Earths: Properties 220
Strength of Materials: Textbook 220
Thermal-Fatigue Cracking 220
Low-Alloy Pressure-Vessel Steel (T.1): Properties, etc. 220
Cavitation-Resistance of Low-Alloy Steels 237

Specifications and Testing

Determination of Thermal Conductivity 26
Shafts in Alloy Steels: Specifications 31
Nickel in Iron and Steel: Textbook 88
Testing of Powder-Metal Components 99
,, ,, Brittleness at Low Temperatures 128
Specifications and Tests: Metals Reference Book 174
Strength of Materials: Textbook 220
A.I.S.I. Standards for Low-Alloy Steels 221

Welding

Flash Welding of High-Tensile Nickel-Alloy Steels 6
Electrodes for Welding Steels: Specifications 31, 234
Welded Nickel-Chromium-Molybdenum Steel 68
Spot Welding of Carbon and Low-Alloy Steels 68
Overlaying of Steel with Nickel Alloys 77, 219
Nickel in Iron and Steel: Textbook 88
Temper-Brittleness in Welding 88
Welding of High-Yield-Strength Steels 112
Transition Temperature of Welded Nickel-Steel Plate 146
Metals Reference Book 174
Pre-Heating for Prevention of Hard-Zone Cracking 190
Carbon and Low-Alloy Steel Arc-Welding Electrodes 190
Brazing of Steels: Textbook 206
Welded Pressure-Vessel Steel (T. 1) 220
Brazing of Titanium to Steels 234

HEAT- AND CORROSION-RESISTING MATERIALS

Analysis and Identification

Determination of Tungsten in Steels 5
,, ,, Molybdenum in Steels 32
Chemical Analysis of Steel: German Practice 47
Determination of Nickel and Other Elements in High-Temperature Alloys 55
Determination of Titanium in High-Alloy Steel 55
Spectrochemical Analysis of High-Nickel Alloys 79
Analysis of Thin Films of Stainless Steel 84
Determination of Selenium in Stainless Steels 98
,, ,, Nickel in High-Alloy Steels 148
,, ,, Cobalt in High-Alloy Materials 201
Identification of Metals and Alloys 206

Clad, Faced and Lined Materials (see also **Welding**)

Welding of Clad Materials: Specifications 31
Hard Facing with Nickel-base Alloys 97, 98, 138, 167
Facing of Pump Plungers 98

Page

Monel-Clad Steel in Marine Protection 120, 167
Spray-Metallized Coatings 138
Potential Use of Hard-Facing in Nuclear Power Plants 164
Deposition of Hard-Facing Alloys in Powder Form 167
Cladding of Metals by Vacuum Brazing 175
Ceramic and Metallic Coatings for High-Temperature Service 225

Composition, Constitution and Structure

I. Corrosion-Resisting Materials

Precipitation-Hardening Stainless Steels 2, 16, 194, 198, 224, 236
Rare-Earth Additions to Stainless Steels 34
Low-Nickel, High-Chromium Stainless Steels 35, 197
Cast and Wrought Corrosion-Resisting Materials (A.C.I. and A.I.S.I. Designations) 36
Intergranular Corrosion: Influence of Minor Elements 52, 153
: Influence of Cold Working and Tempering on Structure 77
High-Manganese *vs.* 18-8 Chromium-Nickel Stainless Steels 93, 197
Influence of Neutron Bombardment on Stability 118
Metals Reference Book 174
Molybdenum-containing Corrosion-Resisting Materials: Review 200
Delta Ferrite in Stainless Steels 227, 228
Diffusion of Iron in Austenitic Steels 228

II. Heat-Resisting Materials

Super-Strength High-Temperature Alloys: Typical Compositions: 6 (see also 221)
Nimonic Alloys: Composition and Constitution 8, 149, 151, 160
Sigma Phase:
Influence of Nitrogen on Formation 10
In Weld Metal 11, 39, 96, 233
Mechanism of Formation in Austenitic Steels 33, 70
Etchants for Delineation 39, 121
Magnetic Properties of Sigma-Phase Alloys 107
Properties of Steels in Sigma-Formation Range 134
Formation of Carbide, (Sigma), and Chi Phases in Austenitic Steels 33, 39, 136
Inter-Relation of Structure and Creep in Austenitic Steels 68
Iron-base High-Temperature Casting Alloy 70
Chromium-rich Chromium-Nickel Alloys 86
Surface Layers of Nickel-Chromium Alloys: Influence of Oxidation on Composition 93
Uranium Additions to Cobalt-base Alloys 113
Neutron Bombardment: Influence on Stability 118
Cast Nickel base Alloy G.M.R. 235 133
Titanium-, Boron-, Vanadium-, and Zirconium-modified Austenitic Steels 135
Nickel-Chromium-(Cobalt)-base Nimonic Alloys: Effect of Structure on High-Temperature Properties 149, 150
Boron-containing Cobalt-Chromium-base Alloys 151
Metal-Impregnated Titanium-Carbide Cermets 152
Rare-Earth Additions to Cobalt-Chromium-Nickel-Alloys 160
Metals Reference Book 174
Nickel-Chromium-Carbon Alloys: Constitution 206
Super-Strength High-Temperature Alloys: A.S.T.M. Summary 221 (see also 6)
Jetalloy 1570 222
Gas Turbines and Jet Propulsion: Textbook 222
Structural Changes in Low-Alloy Steels during Creep 222, 223

Page

General

Design and Fabrication: Influence on Performance of Stainless-Steel Equipment 52, 78
Polarization of Nickel and Nickel-Copper Alloys in Sodium Chloride Solution 59
Dry Corrosion: Practical Problems 70, 117
Anodic Protection of Stainless Steel in Nitric Acid 78
Gas Turbines: Design, Materials, etc. 71, 90, 160, 222, 223, 224
Honeycomb Metal Construction 116
Corrosion Inhibitors: Reference Data 118
Neutron Bombardment of Stainless Steel 118
Metal-Impregnated Titanium-Carbide Materials 152
Progress in Alloys of the Nimonic Series: Nimonic 100 160
Metals Reference Book 174
Corrosion Research in the U.S.A. 195
Ceramic Materials for Aircraft Use 225
A.S.M. Metals Handbook: Stainless-Steel Section 235
Materials used in Chemical Engineering: Literature Review 235

Powder Production: Properties and Uses of Powder-Produced Alloys

High-Temperature Materials made by Powder Metallurgy 9, 225
Titanium Carbide/Nickel and Nickel-Alloy Cermets 12, 113, 152, 164, 191
Resistance Sintering of Metal Powders 58
Testing of Sintered-Metal Components 99
Stainless-Steel Components made from Powder 114
Metal-Impregnated Titanium-Carbide Cermets 152
Rolling of Stainless-Steel Strip from Powder 167
Deposition of Hard-Facing Alloys in Powder Form 167

Production and Processing (see also **Welding**)

Heat-Treatment of Nimonic Alloys 6, 62, 149, 160
Fabrication of Poppet Valves, Guides and Seats 12
Precipitation-Hardening Treatment for Stainless Steels 16
Descaling and Cleaning of Stainless Steel 17, 94, 163, 195
Hot Workability: Improvement by Rare-Earth Additions 34
Production of Welded Piping 38
Etching of High-Alloy Materials 39, 121, 200, 227
Manufacture and Fabrication of Nimonic Alloys: Commercial Practice 45, 62, 190 191, 227
Vacuum Melting of High-Nickel Alloys 47
Cutting Fluids for Machining High-Alloy Materials 48, 227
Influence of Heat-Treatment and Cold Work on Austenitic Steel 51, 77, 229
Cold Heading of Stainless Steel 52
Influence of Design and Fabrication on Corrosion-Resistance of Stainless Steel 52, 78
Chemical and Electrochemical Polishing of High-Alloy Materials 58, 152, 164
Production of Wrought Alloys: Symposium 62
Manufacture and Fabrication of Materials used in Aircraft Gas Turbines 45, 63, 71, 90, 190, 191, 227
Production of Austenitic Welding Electrodes 76
Processing of High-Manganese Stainless Steels 93, 197
Production of Stainless-Steel Tankers 94
Manufacture of Cast Alloy G.M.R. 235 133
Influence of Heat-Treatment on Properties of Nickel-Chromium-(Cobalt) Alloys 149, 160, 222
Production and Fabrication of Boron-containing Cobalt-Chromium Alloys 151
Production of Small Holes in Stainless-Steel Sheet 155

Page

Deep Drawing of Nimonic 75 and Stainless Steel 191
Vibrational Treatment of Austenitic Steel Castings during Solidification 195
Heat-Treatment of Jetalloy 1570 222
CeDeCut Process for Machining High-Alloy Materials 227

Properties (see also **Specifications**)

I. Corrosion-Resisting Materials

Precipitation-Hardening Stainless Steels 2, 16, 194, 198, 224, 236
Stability of Austenitic Steel Weights 18
Corrosion of Stainless Steel in High-Temperature Water 19, 154, 196, 230
Corrosion by Phosphoric Acid 19, 230
,, by Conditions in the Petroleum Industry 20
Resistance of Stainless Steel and Nickel-Molybdenum Alloys to Iodine 20
Thermal Conductivity of Steels and Alloys 26, 175
Reaction between Metals and Molten Sodium Hydroxide 27, 60, 164, 176
Mechanical Properties of Shafts of Austenitic Steel 31
Stainless Steels containing Rare Earths: Properties of 34
Low-Nickel, High-Chromium Stainless Steels 35, 197
Atmospheric Corrosion-Resistance of Iron-Nickel-Chromium Alloys 36, 237
Sulphide Corrosion in Oil-Well Equipment 37
Resistance to Sulphuric Acid and Acid Sludges 37
Corrosion by Vanadium Pentoxide 50, 72, 117, 161
Fatigue Strength of Austenitic Steels 51
Mechanical Properties of Cold-Worked Austenitic Steel Wire 51
Intergranular Corrosion in Austenitic Steels: Influence of Carbon and Minor Elements 52, 153
Electrochemical Study 139
Preservation of Corrosion-Resistance during Fabrication 52, 78
Corrosion in the Chemical and Petrochemical Industries 53
Corrosion of Condenser Tubes in Polluted Water 53
Resistance to Hydrofluoric Acid and Fluorine 54, 78, 79, 95, 108
Dry Corrosion at Elevated Temperatures 70, 72, 117, 196
Anodic Protection of Stainless Steel in Nitric Acid 78
Enthalpy and Specific Heat of Nickel-Chromium Alloys, Austenitic Steel and Monel 91
Mechanical Properties of Monel at Normal and Elevated Temperatures 92
Passivity and Corrosion-Resistance of Stainless Steels 93
High-Manganese *vs.* 18-8 Chromium-Nickel Stainless Steels 93, 197
Diffusion of Hydrogen through Stainless Steels 94
Stress-Corrosion in Stainless Steels 95, 198, 199, 226
Corrosion by Agricultural Chemicals 96
Hot Ductility of Stainless Steels 114
High-Temperature Properties of Corrosion-Resisting Steels for Aircraft (H.N.M. Steel) 115, 230
Corrosion-Inhibiting Agents 118
Resistance of Monel to Marine Conditions 120, 167
Low Temperatures: Effect on Properties of Metallic Materials 128, 228
Atmospheric Corrosion-Resistance of Carbon and Low-Alloy Steels 153, 237
Atmospheric Corrosion-Resistance of Copper-base Alloys 155
Corrosion of Austenitic Steel by Chloride Dyes 165
Resistance to Chlorine-Dioxide Bleaches 166
Properties of 17-7 Chromium-Nickel Steel for Structural Use 167, 228
Metals Reference Book 174

Page

Ni-Resist: Corrosion Data 188
Resistance of Stainless Steel to Hydrogen–Chloride Gas 195
Corrosion by Nitric Oxide 196
Corrosion of Chromium–Nickel Steel in Surgical Appliances 199
Molybdenum–containing Corrosion–Resisting Materials: Review 200
Strength of Materials: Textbook 220
Corrosion in Wood–Vinegar Plant 231
,, ,, Locomotive Sheds 231
A.S.M. Metals Handbook: Typical Corrosion Data for Stainless Steel 235
Nickel–containing Materials in Chemical Engineering: Review 236
Cavitation–Resistance of Metals and Alloys 237
Atmospheric Corrosion of Galvanic Couples 237

II. Heat–Resisting Materials

Age–Hardenable High–Temperature Alloys 2
Properties of Typical Super–Strength Alloys: A.S.T.M. Summary 6 (see also 221)
Nimonic Alloys (75, 80, 80A, 90, 95, 100) 8, 26, 70, 149, 150, 152, 160, 222
Nickel–Aluminium Alloys 7
Cast Cobalt–base Alloy (Jessop G.34) 9
Influence of Cyclic Temperature or Load on Properties 10, 32, 91
Oxidation of Nickel–Chromium Alloys 11, 93
Brightray Electrical–Resistance Materials 11, 115
Thermal Conductivity of High–Alloy Materials 26, 175
Creep Properties of Nickel 42
Properties of Vacuum–Melted Alloys 47
Specific Heat of Nickel–Chromium Alloys at High Temperatures 48
Tensile and Compression Tests on Sheet Materials 48
High–Temperature Properties of Steels used in Power Stations 48, 132
Oxidation of Nickel–Molybdenum Alloys 49
Corrosion by Vanadium Pentoxide 50, 70, 72, 90, 117, 161
High–Temperature Properties of Cast Irons 66, 67, 127, 158, 159, 188, 217
Inter–Relation of Structure and Creep in Austenitic Steels 68
Inter–Relation of Long– and Short–Time Mechanical Properties of Nickel–Chromium Alloys 69
Iron–base High–Temperature Casting Alloy 70
Dry Corrosion at High Temperatures: General Reviews 70, 117
Materials used in Gas Turbines: Properties of *see* **Uses, Heat–Resisting Materials**
Monel: Influence of Temperature on Mechanical Properties 92
Uranium–containing Cobalt–base Alloys 113
Hot Ductility of Materials for Steam Turbines 114, 160
High–Temperature Properties of H.N.M. Stainless Steel for Aircraft 115, 230
Nickel Additions to Cast Chromium–Molybdenum Steel 116
Creep of Nickel–Aluminium Bronzes 126
Notch–Fatigue Properties of Nickel–Chromium–Cobalt–Iron Alloy 132
Notch–Rupture Tests on High–Temperature Alloys 132
Cast Alloy (G.M.R. 235) for Gas Turbines 133
Properties of Austenitic Steels at 600°–700°C. 134
Properties of Titanium–, Boron–, Vanadium–, Zirconium–modified Austenitic Steels 135
Oxidation of Cobalt–Nickel Alloys 145
Cast Copper–base Alloys: High–Temperature Properties 146

Page

High–Temperature Properties of Nickel–Chromium–(Cobalt) Alloys (Nimonic Series)
(*a*) Influence of Structure and Heat–Treatment 149
(*b*) Tensile and Torsional Properties 150
Boron–containing Cobalt–Chromium–base Alloys 151
Compression–Creep and Tension–Creep of High–Temperature Alloys 152
Titanium Carbide/Metal–Impregnated Materials 152
Nickel–Tungsten Alloys 153
Nimonic 100 160
Rare–Earth–containing Cobalt–Chromium–Nickel Alloys 160
Static and Fatigue Properties: Inter–Relation of 160
Metals Reference Book 174
Chromium–Copper–Nickel and Chromium–Molybdenum–Vanadium Steels: High–Temperature Properties 192
Properties of Austenitic Steel Castings Vibrated during Solidification 195
Strength of Materials: Textbook 220
Super–Strength High–Temperature Materials: A.S.T.M. Summary 221 (see also 6)
Alloys suitable for Use at High Temperatures (Oxidation– and Creep–Resistance) 221
Jetalloy 1570 222
Materials used in Aircraft: Seminar 222, 223, 224, 225
Selection of Steels for Service up to 1000°F. 225

Specifications (see also **Testing**)

High–Alloy Welding Electrodes: A.W.S./A.S.T.M. Specifications 31, 234
Stainless Steels: U.S. Governmental Specifications 51
Pressure Piping: A.S.A. Proposals 92
Heat–Resisting S.G. Iron: S.A.E./A.M.S. Specification 110
Heat– and Corrosion–Resisting Materials: S.A.E./A.M.S. Specifications 110, 117, 234, 235
Stainless Steel: A.I.S.I. Specifications 118
Alloys and Stainless Steels used in Pressure Vessels 138, 192
Nimonic Alloys 160
Stainless Steel for Structural Use 167
Metals Reference Book 174
Nickel–base Brazing Alloys: S.A.E./A.M.S. Specifications 234, 235
Stainless–Steel Tubing: S.A.E./A.M.S. Specification 235
High–Expansion Nickel–Manganese Steel: S.A.E./A.M.S. Specification 235

Testing (see also **Specifications**)

Cyclic–Temperature Tests (including Thermal–Shock Tests) 10, 15, 32, 134, 220
Testing of Valves for Handling Corrosives 38
Testing of Welds and Electrodes 31, 39, 77, 228, 233
Salt–Spray Test: Acetic–Acid Modification 61, 140
Relationship between Long– and Short–Time Properties in Nickel–Chromium–base Alloys 69
Resistance to Scaling and Attack by Vanadium Pentoxide: Test Technique 72, 161
Pressure Piping: Test Methods 92
Sintered Metal Components: B.S. Test Methods 99
Hot-Ductility Testing 114
High–Temperature Fatigue Testing 134
Intergranular–Corrosion Tests:
Electrochemical Method 139
Oxalic Acid and Acid Copper–Sulphate Tests 200
Boiling Nitric–Acid Tests 200
Nitric–Acid Test Solutions: Influence of Contamination 200

Page

Static and Fatigue Properties: Inter–Relation 160
Corrosion Testing in Marine Conditions: INCO Test Stations 200
Cavitation Test Methods 237
Galvanic–Couple Atmospheric–Corrosion Tests 237

Uses (see also **Clad, Materials, and Powder Production**)

I. Corrosion–Resisting Materials

Stainless–Steel Bellows 15
Stainless–Steel Wire 17, 51, 120
Analytical Weights 18
Equipment used in Production of Phosphoric Acid 19, 230
Nickel–containing Materials in the Petroleum Industry 20
Stainless Steels and Nickel–Molybdenum–base Alloys for Handling Iodine 20
Stainless–Steel Railway Coaches 20
Stainless Steel in Architecture 21
Nuclear Power Plant: Materials for use in 27, 59, 60, 164, 176
Shafts of Stainless Steel 31
Materials for Handling Sulphuric Acid and Acid Sludges in Refineries 37
Valves for Use in Corrosive Conditions 38
Welded Steel Piping 38
Equipment used in the Chemical Industries: Reviews 53, 120, 154, 164, 200, 236
Condenser Tubes 53, 139
Nickel Alloys for Handling Hydrofluoric Acid and Fluorine 54, 79, 95, 108
Austenitic Steel Welding Electrodes 76, 77
Stainless–Steel Tankers 94
Stainless Steel in the Dairy Industry 95, 120
„ „ „ Wine Industry 95
Equipment in Contact with Agricultural Chemicals 96
H.N.M. Stainless Steel for Aircraft 115, 228
Feeding and Proportioning Equipment in Chemical Plant 120
Monel for Protection of Steel in Marine Service 120, 167
Stainless–Steel Rings for Gas Turbines 137, 138
Materials for Pressure Vessels 138, 192
High–Alloy Steels in the Petroleum Industry 154
Stainless Steel in Chemical Plant: Review 164
Cast Nickel–containing Alloys in Pickling Equipment 164
Stainless Steel in Chloride Dyeing Equipment 165
Alloys for Chlorine–Dioxide Pulp–Bleaching Equipment 166
Stainless Steel for Structural Use 167, 228
Materials for Ore–Treating Plant 195
Austenitic Chromium–Nickel Steel in Bone Surgery 199
Molybdenum–containing Materials in the Chemical–Engineering Industries 200
Austenitic Steels for Processing Wood Vinegar 231
Smoke Ducts in Locomotive Sheds 231
Materials used in Chemical Engineering: Literature Review 236
Valves for Handling Corrosive Fluids 236

II. Heat–Resisting Materials

Materials Used in Power Stations 10, 15, 48
Electrical–Resistance Materials: Brightray Alloys 11, 115, 222
Poppet Valves, Guides and Seats 12
Nuclear Power Plant: Materials for Use in 27, 59, 60, 164, 176
Nickel–base Brazing Alloys 34, 50, 74, 75, 97
Materials Used in Aircraft Gas Turbines: Reviews 71, 90, 160, 222, 223
Nimonic Alloys in Gas Turbines 71, 90, 114, 153, 160, 163, 190, 191, 222, 233

Page

Pressure Piping 92, 132
'Honeycomb' Metal Construction 116
Cast Gas–Turbine Blading 133
Welded High–Alloy Steel Rings for Gas Turbines 137, 138
Steels and Alloys for Pressure Vessels 138, 220
Marine Gas–Turbine Components 153
Materials of Construction in Ore–treating Plants 195
High-Alloy Cast Irons for Elevated-Temperature Service: *see* **CAST IRON**
Jetalloy 1570 Gas–Turbine Blading 222
Aircraft Design and Materials: Seminar 223, 224, 225

Welding, Brazing and Soldering, also Gas- and Arc-Cutting (see also **Clad Materials**)

Cyclic–Temperature Tests on Welds 10, 15
Sigma Phase in Weld Metal 11, 39, 96, 233
Elevated–Temperature Properties of Stainless–Steel Welds 13
Resistance Welding of Stainless–Steel Bellows 15
Welding of Precipitation–Hardenable Stainless Steels 16
Specifications for Welding Electrodes 31, 77, 234
Testing of Welds and Welding Electrodes 31, 39, 77, 228, 233
Austenitic Steel Welding Electrodes 31, 76, 77, 96, 233, 234
Nickel–containing Brazing Alloys and Properties of Brazed Joints 34, 50, 74, 75, 97, 192, 206, 234, 235
Production of Welded Nickel–Chromium Steel Piping 38
Fatigue Strength of Spot–Welded Stainless Steels: Effect of Pre-stressing 39
Knife–Line Corrosion in Heat–Affected Zone in Niobium–Stabilized Steel Welds 54, 117
Welding of Stainless Steel: Summary of Information 77
Overlaying of Steel and Cast Iron with Non-Ferrous Metals 77, 219
Welding of Wrought High–Alloy Materials: Avoidance of Hot Cracking 96 (see also 233)
Welding of Rings for Gas Turbines 137, 138
„ „ Steels and Alloys for Pressure Vessels 138
* Joining of Nickel Alloys: Recommended Practice 172
Cladding of Metals by Vacuum Brazing 175
Welding of High–Manganese Stainless Steels 195
Brazing Manual 206
Brazing Alloys: Specifications 206, 234, 235
Properties of Welds in 17–7 Chromium-Nickel Steel 228
Inert–Gas–Shielded Arc Welding of Metals and Alloys 232 (see also 17)
Moisture in Electrode Coatings 233
Brazing of Titanium to Stainless Steel 234

PATENTS 21, 79, 121, 168 (corrigendum 99)

Corrigenda

p. 65. *Right-hand column, line* 7.
Title : *for* 'Nickel Films' *read* 'Nickel-Iron Films.'

p. 106. *Right-hand column, in first table*
for 'pH 12·2-2·8' *read* '12·2-12·8.'

p. 121 *Left-hand column,*
Title *of first* '*patent*' *delete* 'Methyl'

p. 122. *Patent* on Nickel in Aluminium Alloys for Pistons
third line for 'copper 0·1-1' *read* 'cobalt 0·1-1.'

p. 154. *Left-hand column, line* 27,
for '500°F. (120°C.)' *read* '500°F. (260°C.).'

ibid., line 53
for 'Nickel-copper' *read* 'Copper-nickel.'

* *Leading Article*

TRADE-NAMED MATERIALS AND PROCESSES

Referred to in Nickel Bulletin, Volume 28, 1955

16-25-6, 7.
17-4 P.H. 16, 17, 194, 198, 199.
17-7 P.H. 16, 17, 198, 199, 224.
17-22 A.S. 138, 194.
19-9 D.L. 7.

A-286 7, 75, 224.
Admiralty Metal, 155.
Alcomax Alloys, 4, 109, 110.
Alcoplate, 29.
Alnico Alloys, 4, 46, 109.
Alumel, 42, 175.
A.M. 350 Steel, 35.
A Nickel, 101, 231.
Armco Iron, 209.
Armco 17–4 *P.H.* See **17-4 P.H.**

B Nickel Powder, 21.
Brightray Alloys, 12, 101, 115.

C.A. Alloys, 36.
Calgon, 165.
Calorizing Process, 225.
Carpenter 20, 231.
Cathaloy Alloys, 100.
C.B. Alloys, 36.
C.C. Alloys, 36.
C.E. Alloys, 36.
CeDeCut Process, 227.
C.F. Alloys, 36, 165.
C.H. Alloys, 36.
Chlorimet, 37, 53, 79, 166.
Chromac N Electrodes, 173.
Chromel, 42, 76, 175.
Chro-Mow Steel, 116.
C.K. Alloys, 36.
C.N. Alloys, 36, 165.
Colmonoy, 53, 76, 98, 167, 237.
Columax, 4, 109, 110.
Constantan, 42, 175.
Corrodkote, 183.
Corronel B, 172, 173, 232.
Corten Steel, 228.
Crucible H.N.M. Steel: See **H.N.M. Steel.**
Cunico, 46.
Cunife, 46.

Dalic Brush-Plating Process, 44.
Deltamax, 31.
Discaloy 24, 7.
Dowex 1, 55.
Duranickel, 2.
Durichlor, 166.
Durimet 20, 9, 166, 167.
Duriron, 166.

Ferroxdure, 46.
Ferry, 101.
Firth-Vickers 467, 71.
Fix Invar, 87.
F.S. Cermets, 49.

G.39. See **Jessop G.32**, etc.
G.F.A. Nickel, 101.
G.E. 76, 50.
G.M.R. 235, 133, 134.

Halcomb 218, 115.
Hastelloy Alloys, 20, 37, 53, 76, 79, 117, 120, 166, 176, 224, 225.
Haynes Alloys: (*see also* **Hastelloy Alloys**), 7, 20, 53, 76, 152, 224, 225, 237.
H.N.M. Steel, 115, 230.
H.P.A. Nickel, 101.
H.P.B. Nickel, 101.
Hortonclad, 176.
H.R. Crown Max, 195.
Hydride Process, 50.
Hy-Tuf, 48.

Illium R, 54, 231.
Inco 131 Electrode, 172.
Inco 132 Electrode, 173.
Incoloy, 225.
Inconel, 3, 8, 32, 53, 74, 75, 76, 77, 98, 101, 108, 117, 154, 166, 172, 173, 195, 196, 205, 220, 224, 231, 232.
Inconel X, 7, 8, 9, 33, 48, 116, 133, 138, 149, 224.
Invar, 87.

Jessop G.32, G.34 and G.39, 9, 72, 73.
Jessop G.42, 71.
Jetalloy 1570, 222.

K. 162-B Cermet, 152.
Kanigen Electroless Plating Process, 28, 29, 44.
Kanthal A-1, 76.
Kelcaloy Joints, 10.
K Monel, 2, 3, 77, 98, 154, 172, 232.
Konal, 208.
Koroseal, 61.

LaBour R-55, 166.
Lubrite Surface Finish, 158.
Lustraloy, 28.

M-252, 7, 47, 79, 224.
Malcomizing Process, 154.
Mercasting Process, 90.
Metamic LT-1, 152.
Minovar, 159.
Molybdenum-Permalloy: (*see also* **Permalloy** and **Supermalloy**), 187.
Monel, 3, 20, 22, 26, 32, 37, 38, 53, 54, 59, 76, 77, 78, 79, 91, 92, 108, 117, 120, 139, 154, 156, 166, 167, 172, 219, 220, 232, 237.
Multimet: See **N-155 Multimet.**
Mumetal, 187.

N-80 Steel, 37, 198.
N-155 Multimet Alloy, 7, 33, 96, 116, 132, 149, 160, 225.
Nialite, 3.
Nichrome V, 50.
Nicrex 4 Electrodes, 173.
Nicrobraz, 50, 192, 225.
Nife Batteries, 143.
Nilo Alloys, 101.
Nimonic Alloys—
Nimonic 75, 71, 72, 138, 150, 151, 153, 172, 173, 191, 232, 233.
Nimonic 80 and 80A, 26, 70, 149, 150, 151, 152, 153, 160, 163, 172, 173, 190, 191, 205, 233.
Nimonic 90, 8, 101, 149, 150, 151, 152, 153, 160, 172, 173, 191, 233.
Nimonic 95, 8, 71, 150, 151, 160, 222, 227.
Nimonic 100, 160.
Nimonic Alloys, General, 45, 48, 71, 114, 149, 220, 222, 225, 232.
Nimonic DS, 172, 173.
Ni-Resist, 37, 66, 130, 159, 188, 217, 218.
Ni-Rod and Ni-Rod 55, 219.
Ni-Span C, 2, 101.
Ni-Vee Bronzes, 146.
No-Mag, 217.

O Nickel, 101.

Permalloy: (*see also* **Molybdenum - Permalloy** and **Supermalloy**), 31, 65, 187, 216.
Perminvar, 31.
P.H.20 Steel, 236, 237.
P.H.55 A, B, and C Steels, 236, 237.
Pyrex, 237.

R.23 Steel, 72.
Raney Nickel Catalyst, 179, 207, 208.
RC-130-A Titanium, 33.
R.ex 448, 227.
Refractaloy 26, 7.
S-590, 7.
S-816, 7, 9, 133, 151, 152, 224.
Shell Moulding (C) Process, 46.
Silmanal, 46.
S Monel, 2.
S.P.M. 1 and 2, 173.
Spraywelding Process, 97.
Stainless W Steel, 16, 48.
Stellite-type Alloys: See **Haynes Alloys.**
Supermalloy. (*see also* **Molybdenum - Perm - alloy and Permalloy**), 31.
Super Nickel 826, 76.

Timken 17-22 *A(S)*: See **17-22 A.S.**
T.B.L. Process, 167.
Tracerlab Gas Counter, 144.
T-1 Steel, 220, 221.

U.S. Navy M. Bronze, 146.

Vectolite, 46.
V 2B Steel, 16, 17.
Vinyon, 44.
Virgo Salts, 18.
Vitallium, 7.
Vycor, 10, 11.

Wall Colmonoy: See **Colmonoy.**
Waspaloy, 133.
Wiggin Welding Electrodes, 172, 173.
Worthite, 79.
W.Z. Cermets, 191, 192, 193.

X-40 Alloy, 7, 9, 152.

Yoloy Steel, 228.

Binders bearing the date 195- and suitable for 1955 and 1956 Nickel Bulletins are now available. We shall be pleased to send one free of charge.

NAME INDEX TO VOLUME 28

Abdine, H. 209.
Adams, R. L. 166.
Adler, A. 114.
Agrawal, K. C. 2.
Alesch, C. W. 224.
American Chemical Society, 213.
American Electroplaters' Society, 85, 86, 105, 182, 183.
American Institute of Chemical Engineers, 59
American Iron and Steel Institute, 196, 221.
American Society for Metals, 205, 235.
American Society for Testing Materials, 6, 31, 32, 61, 128, 155, 163, 190, 200, 221.
American Society of Mechanical Engineers, 192.
American Standards Association, 92.
American Welding Society, 190, 206, 234.
Amlie, R. F. 184.
Ammareller, S. 67.
Andrew, J. F. 104.
Apps, R. L. 209.
Araki, T. 215.
Armstrong, T. N. 146.
Ault, G. M. 9.
Averbach, B. L.215 .

Babcock, R. S. 108.
Bachmann, P. 93.
Baerlecken, E. 136.
Baillie, Y. 227.
Balas, W. 208.
Baldwin, E. E. 91.
Baldwin, W. M. 52.
Banewicz, J. J. 102.
Banks, R. L. 102.
Barr, H. N. 214.
Battelle Memorial Institute, 138.
Baur, H. 58.
Beach, J. G. 59.
Beaver, H. O. 34.
Bechtoldt, C. J. 33.
Beck, F. H. 59, 78.
Beck, P. A. 107.
Beiser, C. A. 52.
Benard, J. 11.
Bendure, R. J. 200.
Bennett, J. A. 26, 148.
Bentley, N. E. 104.
Berry, W. E. 19.
Betteridge, W. 63, 149, 161, 221.
Bibber, L. C. 221.
Bigg, P. H. 18.
Bisson, E. E. 205.
Blanpied, W. A. 26.
Blatz, W. E. 151.
Blois, M. S. 65, 216.
Bloom, F. K. 198.
Blumenthal, H. 191.
Boas, W. 207.
Boegehold, A. L. 133.
Bolsover, G. R. 154.
Bolton, J. 38.
Böltz, G. 84.
Bott, H. B. 77: see also 219.
Bounds, A. M. 100.
Bowen, I. G. 90.
Boyd, P. B. 207.
Boyer, W. J. 98.
Bozorth, R. M. 217.
Bradley, P. 233.
Bradley, W. W. 213, 237.
Bradstreet, B. J. 190.
Brailsford, F. 65.
Braumann, F. 70, 121.
Brasunas, A. de S. 36, 50.
Brauns, E. 139.
Breen, J. E. 160.
Brenkman, J. A. 30.
Brenner, A. 28, 105.
Brenner, S. S. 49.
Briggs, J. Z. 200.
Briggs, T. H. 100.
Bright, H. A. 55.
British Cast Iron Research Association, 158, 188.
British Iron and Steel Research Association, 5, 32, 67, 148, 153.
British Standards Institution, 99, 112, 113.
British Welding Research Association, 68.
Britton, E. C. 180.
Britton, S. G. 104.
Brook, G. B. 87.
Brooke, M. 118.
Brown, E. L. 176.
Brown, H. 78, 158.
Brown, W. F. 192.
Brune, F. G. 212.
Brush, E. G. 164.
Bryan, G. M. 195.
Bucher, J. B. 90.
Bucklow, I. A. 103.
Budberg, P. B. 153.
Bungardt, K. 68.
Bünger, J. 230.
Bunk, A. P. 112.
Burch, F. H. 18.
Burgess, H. 144.
Burns, R. M. 213.
Burton, T. L. 224.
Byrn, E. E. 27.

Camidge, L. 233.
Campbell, J. B. 68.
Campbell, M. E. 27.
Carlson, R. L. 132.
Caron, M. H. 177.
Carroll, J. W. 85.
Carter, A. D. S. 90.
Casagrande, R. M. 101.
Catalano, E. 211.
Caughey, R. H. 32.
Chadwell, A. J. 207.
Challansonnet, J. 100.
Changarnier, J. 53.
Chase, H. 158.
Cheek, C. 228.
Cheshire, L. J. 90.
Child, H. C. 9, 72, 113.
Chinn, J. L. 144.
Chipman, J. 83, 186.
Choquet, A. 39, 228.
Cina, B. 77, 78.
Clark, A. 102.
Clark, F. E. 224.
Clark, H. C. 28.
Clarke, S. G. 104.
Claussen, G. E. 13.
Clegg, A. G. 109.
Clifford, C. B. 108.
Codell, M. 210.
Coffin, L. F. 32.
Cohen, M. 215.
College of Aeronautics, Cranfield, 195.
Collier, T. W. 63.
Collins, J. A. 52.
Colwell, A. T. 90.
Commission d'Etude des Métaux á Chaud de l'Irsid (Institut de Recherches de la Sidérurgie), 48.
Compton, K. G. 237.
Comstock, G. F. 131.
Conger, R. L. 186.
Conway, C. G. 90.
Copestake, L. G. 90.
Cordier, J. A. 186.
Corey, C. L. 13.
Corey, J. W. 180.
Cornell Aeronautical Laboratory, 135.
Corner, W. D. 100.
Cornet, I. 145.
Corson, J. H. 17.
Cottrell, C. L. M. 190.
Cound, T. E. 63.
Cox, H. Roxbee, 90.
Cross, H. C. 6, 33.
Culbertson, R. P. 96.
Curran, R. M. 96; see also 233.
Curtiss, L. O. 224.
Cuthbertson, J. W. 105.

Dana, A. W. 189.
Darnell, A. J. 196.
Davis, C. S. 223.
Davis, H. W. 177, (corrig. 99).
DeLong, H. K. 106.
Demirjian, S. G. 224.
Dempsey, J. 208.
Denaro, L. F. 42.
Dennison, J. P. 126.
Desorbo, W. 185.
Deutsch, G. C. 9.
Dever, J. L. 91.
Diaz, R. 107.
Dickinson, T. A. 15, 138.
Dietzler, A. J. 180.
Digges, T. G. 42, 92.
Diggin, M. B. 28.
Dixon, H. E. 68.
Dorn, J. E. 32.
Doty, W. d'O. 220.
Douglas, D. L. 230.
Douglas, T. B. 91.
Drake, R. T. 176.
Dravnieks, A. 178.
Dreyer, H. 179.
Driscoll, D. E. 143.
Druschel, M. L. 27.
Dudzinski, N. 157.
Dykstra, J. 108.
Dyrkacz, W. W. 151.
Dyroff, G. V. 27.

Eberle, F. 15.
Eden, T. F. 50.
Edmunds, W. T. 63.
Edwards, J. O. 146.
Ehrenberg, D. M. 196.
Eisenberg, P. H. 213.
Eisermann, F. 70, 116.
Eisler, S. L. 156.
Ellis, A. T. 237.
Ernst, D. W. 184.
Esveldt, C. J. 47.
Evans, E. R. 158.
Everest, A. B. 219.
Everhart, J. L. 2.
Faint, H. 44.
Farber, M. 196.
Farnsworth, H. E. 59.
Farrar, R. L. 211.
Fassnacht, W. G. 6.
Faust, C. L. 59.
Feilden, G. B. R. 90.
Feiler, C. E. 78.
Field, A. J. 62.
Finch, G. I. 84.
Finch, L. G. 64.
Finigan, C. M. 180.
Flaschka, H. 209.
Fleischmann, W. L. 15, 54
Fletcher, W. D. 214.
Flint, G. N. 93.
Flint, P. S. 94.
Foerster, C. V. 97.
Foley, R. T. 187.
Fontana, M. G. 59, 78, 200.
Forshaw, J. R. 90.
Forward, F. A. 83.
Fowler, R. 230.
Francisco, A. C. 192.
Frankel, H. E. 148.
Fraser, J. P. 37.
Frederick, S. F. 145.
Frederick, S. H. 50.
Frey, D. 32, 33.
Frith, P. H. 111.
Fritzsche, O. H. 98.
Fry, H. 103.
Fullerton, H. V. 180.
Fulton, K. T. 71.
Funk, C. W. 16.

Galt, J. K. 216.
Gamble, L. W. 210.
Gattringer, R. 110.
Geldermans, P. 47.
General Electric Company, 94, 230.
Gerber, W. O. 79.
Giger, G. A. 101.
Gilbert, G. N. J. 66, 130, 188.
Gilles, P. 227.
Ginsberg, H. 215.
Glagoleva, V. P. 45.
Glaister, E. 90.
Glaser, F. W. 113, 114, 191.
Goddeyne, D. J. 61.
Goddeyne, L. D. 61.
Godfrey, D. 205.
Goetzel, C. G. 152.
Gordon, E. 6.
Gore, R. T. 214.
Gorter, E. W. 47.
Goswami, A. 84.
Graham, A. 69.
Grala, E. M. 8.
Granger, M. J. 16.
Grant, N. J. 86.
Gray, A. J. 60.
Green, D. W. 47.
Greene, R. J. 159.
Grilliat, J. 66.
Grodner, A. 38.
Groth, V. J. 37.
Grubb, P. E. 183.
Gruzin, P. L. 186.
Guard, R. W. 222.
Guarnieri, G. J. 33, 152.
Guerreiro, A. 224.
Guldner, W. G. 208.
Gundzik, R. M. 78.
Gurland, J. 20.
Gutzeit, G. 44, 86.
Gyorgak, C. A. 192.
Hafsten, R. J. 37.
Hague, J. L. 55.
Hale, A. L. 233.
Hall, A. M. 88.
Hall, H. F. 189.
Hall, L. E. 104.
Hall, N. 45, 61.
Halliday, J. S. 102.
Halsbury, Earl of, 104.
Hambling, S. K. 90.
Hamilton, J. L. 52.
Hammer, E. W. 167.
Hammond, R. A. F. 102, 105.
Hanink, D. K. 133.
Hansen, S. 153.
Harris, G. T. 9, 72, 113.
Harrison, E. R. 101.
Harrow, G. A. 43.
Hartkamp, H. 181.
Hartleif, G. 131.
Haynes, R. 3, 87.
Heath, A. R. 107.
Heath, S. B. 180.
Hector, L. G. 60.
Heger, J. J. 52, 95.
Hehemann, R. F. 5.
Heikes, R. R. 210.
Henderson, M. A. 156.
Henke, R. W. 120.
Hennie, G. see
Hennig, G. 4.
Hensley, J. W. 211.
Hickling, A. 104.
Hijikata, K. 157.
Hill, J. B. 197.
Hinchliff, S. 195.
Hinde, J. 232.
Hinds, G. P. 102.
Hirst, W. 102.
Hirsch, W. 136.
Hirth, J. P. 78.
Hoar, T. P. 103.
Hobbis, L. C. W. 101.
Hodge, R. I. 90.
Hodges, H. 11.
Hogan, J. P. 102.
Holmberg, E. G. 236.
Holt, M. L. 184.
Hook, I. T. 185.
Hooper, J. E. 233.
Horn, E. 70.
Houston, E. G. 32.
Hoyt, W. B. 32.
Hudson, J. C. 153.
Huffmann, J. W. 224.
Hughes, P. J. 48.
Huhta, H. 31.
Hume-Rothery, W. 126.
Hunt, G. H. 100.
Hunter, J. G. 181.
Hurley, T. F. 90.
Hüttig, G. F. 206.
Hyler, W. S. 132.
Hysel, V. B. 63.

Inge, J. E. 48.
Institute of Metals, 62.
International Nickel Company, Inc. 95, 180, 188, 217.
Iron and Steel Institute, 111.

Jacobson, M. I. 75.
Jaffe, L. D. 88, 89.
Jamieson, A. W. H. 90.
Jenkins, H. A. H. 104.

Jenkins, W. D. 42, 92.
Jepson, S. 103.
Jerrard, H. G. 155.
Johannes, K. P. 233.
Jones, J. W. 195.
Jones, M. H. 192.
Jones, W. H. 210.
Johnson, A. E. 12.
Johnson, C. R. 42, 92.
Johnson, R. L. 205.

Kabermann, S. 214.
Karten, S. M. 29.
Kattus, J. R. 127.
Katz, S. 108.
Kauhausen, E. 76.
Kenigsberg, M. 181.
Kerr, J. A. 72.
Kiessler, H. 68.
King, C. S. 90.
Kinsler, M. R. 223.
Kirkby, H. W. 132.
Kirslis, S. S. 207.
Klebanow, H. L. 50.
Klein, G. 62.
Klitzing, K. H. von, 109.
Knight, F. 65.
Knolls Atomic Power Laboratory, 94, 230.
Knopp, W. V. 6.
Koch, A. J. J. 45.
Kopituk, R. C. 97.
Kornfeld, H. 131.
Kornilov, I. I. 45, 153.
Köster, W. 3, 214.
Krächter, H. 70.
Kraft, R. W. 67, 131.
Krainer, H. 110.
Kraus, F. 58.
Krisch, A. 222.
Krivobok, V. N. 39, 129, 228.
Kroneis, M. 110.
Kunze, E. 68, 70.
Kuo, K. 227.
Kurbatov, M. H. 99.
Kurtz, A. D. 215.
Kuznetsov, E. V. 186.

Lad, R. A. 27.
Lake, A. 85.
Lancaster, C. J. 154, 196.
Landecker, L. 60.
Landon, R. W. 44.
Lane, J. R. 160.
Langenbeck, W. 179.
Lanning, W. C. 102.
LaQue, F. L. 38, 199.
Lavender, J. D. 78.
Lawson, A. E. 48.
Layton, D. N. 104, 105.
Leeser, D. O. 176.
Lena, A. J. 35.
Lenel, F. V. 58.
Levy, A. V. 224.
Lewis, H. 161.
Lewis, W. J. 234.
Lewis, W. N. 74.
Leyda, W. E. 13.
Lien, G. F. 15.
Lihl, F. 64, 156.
Lilljekvist, G. 153.
Lincoln, R. A. 167.
Lindsay, R. 102.
Lines, H. 208.
Linford, H. B. 183.
Linnenbom, V. 228.
Lloyd, R. C. 63.
Long, J. V. 225.
Long, R. A. 34.
Loria, E. A. 115, 230.
Lorig, C. H. 128.
Lorking, K. F. 152.
Low, B. B. 220.
Low, J. R. 118.
Low, S. 219.
Lowrison, G. C. 19.
Lucas, G. 117.
Luce, W. A. 236.
Luke, C. L. 27.
Lula, R. A. 197.

Mackiw, V. N. 83.
Maczkowske, E. E. 55.
Maesen, F. van der, 30.
Malamand, F. 93.
Malatesta, L. 102.
Mamen, C. 143.
Manire, B. L. 224.
Marley, J. L. 201.
Marshall, T. 231.
Martin, D. C. 75, 138.
Martinaglia, L. 67.
Martius, U. M. 179.
Masumoto, H. 48, 108.
Matthews, N. A. 67.
Maurin, A. J. 53.
Maxwell, W. A. 8.
Mayne, C. R. 129.
Mazzoleni, F. 108.
Macdonald, R. J. 132.
McDowell, K. H. 233.
McEnally, V. L. 212.
McKechnie, R. K. 47.
Maclean, J. D. 29.
McMaster, W. D. 61.
McMillan, W. D. 177.
Meecham, S. 103.
Meerbott, W. K. 101, 102.
Melville, W. S. 65.
Mendelsohn, L. I. 46.
Mendizza, A. 237.
Menis, O. 27.
Menyuk, N. 187.
Merritt, F. R. 216.
Michel, R. 92.
Mikula, J. J. 210.
Miller, H. J. 62.
Miller, H. S. 97.
Miller, J. 32.
Milner, D. R. 209.
Ministry of Supply, 107.
Mints, R. S. 45.
Modjeska, R. S. 44.
Mohler, J. B. 107.
Mohrnheim, F. A. 85, 105.
Mond Nickel Company, Ltd. 31, 47, 172, 219.
Montague, B. W. St. Leger, 65.
Montillon, G. H. 108.
Moore, D. C. 232.
Moore, G. E. 208, 209.
Moore, W. F. 47.
Moreau, J. 11.
Morrison, J. 209: see also
Morrison, J. A. 179.
Morton, B. B. 120.
Moss, M. 99.
Muhlenbruch, C. W. 129.
Mundel, A. B. 143.
Muraca, R. F. 86.
Muter, J. R. 176.

Nashner, S. 177.
National Advisory Committee for Aeronautics, 8, 12, 48, 78, 160, 192, 205.
National Association of Corrosion Engineers, 37, 117, 118.
National Fire Protection Association, 220.
Needham, J. C. 232.
Nehring, D. 179.
Nevitt, M. V. 107.
Newman, D. P. 192.
Newman, R. 157.
Newman, W. A. C. 4.
Nichols, R. W. 189.
Nicholson, A. 104.
Nielsch, W. 84.
Nippes, E. F. 54, 114, 117.
Nishimura, S. 101.
Nixon, F. 71.
Noble, H. J. 225.
Noddings, C. R. 180.
Nolan, T. J. 94.
Noren, T. 13.
Norwitz, G. 210.
Numakura, K. 45.
Nylin, J. 167.

Odell, A. L. 28.
Oding, I. A. 51.
Okamoto, S. 215.
Opel, P. 67.
Organization for European Economic Cooperation, 42, 53.
Oriani, R. A. 185.
Ormont, B. F. 210.
Orton, L. H. 232.

Page, B. L. 87.
Paine, T. O. 46.
Parks, J. M. 233.
Parr, J. G. 185.
Payson, P. 4.
Pearlstein, F. 184.
Pease, G. R. 77: see also 219.
Pepkowitz, L. P. 201.
Petersen, R. E. 167.
Pfaffinger, K. 191, 192.
Pfeiffer, I. 178.
Pfeil, L. B. 70.
Phillips, A. L. 206.
Piatti, L. 101.
Pick, H. J. 103.
Pier, G. 121, 139.
Pinner, W. L. 182.
Plesset, M. S. 237.
Polonis, D. H. 185.
Poole, D. M. 126.
Poole, L. K. 11.
Pope, J. G. 180.
Porter, J. J. 19.
Postl, W. S. 208.
Potter, R. D. 42.
Powell, E. W. 108.
Powell, R. L. 26.
Powell, R. W. 26, 175.
Prater, T. A. 222.
Pray, H. A. 19.
Preece, A. 117.
Prosser, S. B. 48.

Quick, G. W. 26.

Rädeker, W. 220.
Rait, J. R. 64.
Ramshage, B. 13.
Rankin, A. W. 96: see also 233.
Rawuka, A. 224.
Reeve, L. 195.
Reilly, P. M. 180.
Renshaw, W. G. 197.
Rexer, E. F. 208.
Reynolds, E. E. 151.
Reynolds, M. B. 118.
Rhodin, T. N. 84.
Richard, C. D. 100.
Richards, J. 100.
Richardson, B. 180.
Rienäcker, W. 216.
Rieppel, P. S. 234.
Rinebolt, J. A. 129.
Rinehart, W. G. 233.
Ring, R. D. 211.
Rittner, H. 3.
Roberts, K. H. 55.
Robertson, J. H. 27.
Rohrer, K. L. 181.
Rose, A. S. 74.
Rose, K. 175.
Rosenberg, H. M. 99.
Rostoker, W. 87, 186.
Rostron, A. J. 104.
Rowan, G. E. 94.
Rowling, H. 90.
Royal Mint, Deputy Master and Comptroller of, 4.
Rubinstein, M. 44.
Ruppender, R. R. 34.
Ruttan, G. D. 176.

Sacco, A. 102.
Sachs, G. 192.
Sachs, K. 161.
Salkovitz, E. I. 215.
Saller, H. A. 50.
Salt, F. W. 103.
Samans, C. H. 10.
Samuel, P. 64.
Sandiford, F. G. C. 233.
Sandoz, G. 65.
Sartor, A. F. 101.
Saunders, O. A. 90.
Say, M. G. 65.
Scheible, H. G. 214.
Schindler, A. I. 215.
Schlotel, R. H. 90.
Schneider, H. C. 213.
Schoefer, E. A. 36.
Schrader, A. 223.
Schreiber, C. F. 96.
Schussler, M. 54, 95.
Schwartzbart, H. 220.
Scott, C. G. 207.
Sefing, F. G. 159, 217.
Sen, B. 211.
Serfass, E. J. 86.
Sewell, J. F. 154.
Shamaiengar, M. 208.
Shapiro, J. 90.
Sharp, W. H. 225.
Shaw, J. D. 6.
Sheehan, J. P. 220.
Sheffield, F. C. 222.
Shenker, H. 174.
Shepard, L. A. 32.
Shilling, W. G. 62.
Shirakawa, Y. 45.
Shishkova, A. P. 51.
Shortsleeve, F. J. 189.
Shull, C. G. 157.
Shyne, J. J. 214.
Siegfried, W. 70, 116.
Simmler, J. R. 55.
Simmons, W. F. 6, 33, 132.
Simon, S. L. 27.
Simons, E. M. 60.
Sinclair, R. M. 231.
Singer, S. E. 99.
Sinha, K. P. 84.
Sinnott, M. J. 214.
Skiba, P. 27.
Skolnick, L. P. 152.
Slick, E. C. 43.
Smagina, I. 210.
Smith, A. G. 90.
Smith, C. Gordon, 65.
Smith, D. C. 233.
Smith, E. M. 87.
Smith, G. G. 222.
Smith, G. V. 32.
Smith, H. A. 207, 211.
Smith, N. D. P. 104.
Smith, R. A. 149.
Smithells, C. J. 174.
Smoluchowski, R. 144.
Snider, A. B. 43.
Snyder, J. 224.
Society of Automotive Engineers, 110, 117, 118, 120, 216, 217, 223, 234, 235.
Soldan, H. M. 10.
Spachner, S. 186.
Specker, K. 181.
Speller, F. N. 165.
Spengler, H. 63.
Spice, J. E. 43.
Sprissler, B. 167.
Stacey, J. T. 50.
Stackpoole, R. W. de Vere, 104.
Stang, J. H. 60.
Stanley, J. K. 10.
Stanners, J. F. 153.
Stauss, H. E. 65.
Staveley, L. A. K. 43.
Stein, C. 86.
Stone, I. 181.
Storchheim, S. 51, 167.
Stout, J. W. 211.
Strobach, W. 183.
Such, T. E. 212.
Sugihara, M. 48.
Sullivan, L. O. 118.
Susano, C. C. 27.
Swalin, R. A. 143.
Swikert, M. A. 205.
Sychrovsky, H. 68.
Sykes, K. W. 179.

Takahashi, M. 48.
Tallis, W. G. 150.
Taniguchi, S. 215.
Taylor, E. A. 232.
Taylor, G. W. 180.
Taylor, J. K. 105.
Teeple, H. O. 166, 236.
Teichner, S. J. 179.
Tetenbaum, M. 228.
Thielsch, H. 39, 77.
Thien-Chi, N. 100.
Thomas, R. D. 15.
Thompson, V. R. 138.
Thorneycroft, D. R. 232.
Tiktinsky, M. 224.
Tilden, E. F. 217.
Timmerbeil, H. 66.
Tisinai, G. F. 10.
Tobin, W. H. 79.
Todhunter, H. A. 139.
Toft, L. H. 93.
Torkar, K. 206.
Tour, S. 138.
Townsend, S. C. 179.
Tracy, A. W. 155.
Trainer, R. P. 101.
Treseder, R. S. 37.
Trewby, G. F. A. 90.
Troiano, A. R. 5, 189.
Tuthill, S. M. 55.
Tyler, W. W. 157.

Upton, H. E. 90.
Urushibara, Y. 101.
U.S. Atomic Energy Commission, 19, 43, 50, 167.
U.S. Bureau of Mines, 177.
U.S. Department of Commerce, Office of Technical Services, 59.
U.S. National Bureau of Standards, 26, 33, 42, 55, 87, 91, 92, 174.
U.S. Naval Engineering Experiment Station, Annapolis, 154, 196.
U.S. Steel Corporation, 148.
U.S. Wright Air Development Center, 195.

Vacher, H. C. 33.
Vagi, J. J. 138.
Valentiner, S. 145.
Vanick, J. S. 129.
Verma, M. R. 2.
Versagi, F. J. 143.
Vidal, G. 93.
Vletter, D. R. de 207.
Vogels, H. A. 76, 134.
Voldrich, C. P. 234.
Vos, K. J. de, 45.

Walker, P. M. 104.
Wallbank, A. W. 104.
Walles, K. F. A. 69.
Walters, R. E. S. 64, 187.
Ward, E. D. 150.
Warncke, H. 58.
Warner, W. L. 146.
Watson, K. 95.
Watter, M. 167.
Waugh, H. C. 77: see also 219.
Wawrousek, W. 54.
Weatherstone, R. T. 233.
Webb, C. R. 31.
Webbere, F. J. 133.
Weddle, M. 117.

Weihrich, R. 47.
Wein, S. 59.
Weinberg, M. 85.
Weiner, R. 62.
Weisberg, H. 10.
Weitzer, H. H. 206.
Welding Research Council, 39, 77, 88, 112, 114, 233.
Welter, G. 39, 228.
Wesley, W. A. 183.
Wesselhöft, E. 109.
West, P. W. 211.
Westman, A. E. R. 85, 105.
Wetternik, L. 231.
Wever, F. 222, 223.
Whittaker, A. 28.
Wiester, H. J. 222.
Wigg, R. E. 90.
Wiggin, Henry, & Company, Ltd. 3, 8, 11, 20, 101, 115, 160, 232.
Wilkinson, M. K. 157.
Wijn, H. P. J. 47.
Wilks, C. R. 67.
Willging, J. F. 78.
Williams, A. J. 217.
Williams, C. 102.
Williams, G. I. 87.
Wilman, H. 104.
Wilson, H. J. 164.
Wolff, P. H. W. 90.
Wolff, R. H. 156.
Wood, D. R. 110.
Woodbury, H. H. 157.
Woodcock, R. F. 59.
Wooten, L. A. 208, 209.
Wriedt, H. A. 83.
Wright, D. A. 101.
Wylie, R. D. 13, 15.
Yager, W. A. 216.
Yamamoto, M. 215.
Yerkovich, L. A. 152.
Yokosuka, S. 210.
Yoshida, S. 215.
Young, C. B. F. 183.
Young, J. G. 233.
Yukawa, S. 214.
Zapffe, C. A. 199.
Zhdanov, G. S. 45.
Zick, L. P. 221.
Zitter, H. 231.
Zyzes, F. C. 230.

PATENTS INDEX

A. P. V. Company, Ltd. 82.
Armco Steel Corporation, 23, 82, 124.

Bacon, F. T. 80.
Badische Anilin - und Soda-Fabrik, A.G. 21, 121, 168.
Baker and Company, Inc. 170.
Baumstark, G. 168.
Beam, W. M. 170.
Beecham, S. W. 21.
Belitz, H. G. 22.
Berk, F. W. & Company, Ltd. 21.
Bethlehem Steel Company, 81.
Betteridge, W. 81, 123, 169.
Binder, W. O. 22.
Binstock, M. H. 122.
Bishop, C. R. 22.
Bloom, F. K. 23.
Bochumer Verein, A. G. 81.
Bofors, A.B. 23.
Böhler, Gebr. & Company, 23.
Botham, G. H. 82.
Bristol Aeroplane Company, Ltd. 170.
British Driver Harris Company, Ltd. 81, 123, 168.
British Electrical and Allied Industries Research Association, 80.
British Thomson - Houston Company, Ltd. 122.
Brown, H. 80.
Buck, J. G. 21.

Callaway, S. R. 23.
Charlesworth, P. A. 24, 80.
Chemical Construction Corporation, 79.
Child, H. C. 169, 170.
Childers, A. H. 168.
Chow, J. G. 23.
Cieslicki, M. E. 22.
Clark, C. C. 122.
Clarke, W. C. 124.
Commonwealth Engineering Company, 22, 80, 121.
Cooper Alloy Foundry Company, 124.
Crafts, W. 123.
Crehan, W. J. 21, 22.
Crucible Steel Company of America, 23, 169.
Culbertson, R. P. 124.
Curtiss-Wright Corporation, 170.

Davis, O. F. 22.
Dawson, D. W. O. 82.
Deutsche Edelstahlwerke, A.G. 22, 23, 169.
Driver-Harris Company, 23, 81.
DuRose, A. H. 80.

Electropol, Ltd. 80.
English Electric Valve Company, Ltd. 168.
Emery, R. St. J., 21.
Epstein, S. 81.
Esercizio dell'Istituto Sperimentale dei Metalli Leggeri, S.A. 122 (corrig. 99).
Ethyl Corporation, 21.
Eutectic Welding Alloys Company, Ltd. 82.
Evans, C. T. 23.

Fine, M. E. 81.
Fink, A. O. 80.
Foley, F. B. 122.
Fouch, C. F. 124.
Fox, L. P. 21.
Franklin, A. W. 123, 169.
Freienstein, E. 21.
Frith, P. H. 170.

General American Transportation Corporation, 21, 22, 80, 168.
General Electric Company, Ltd. 80, 123.
General Electric Company (U.S.A.), 81.
General Motors Corporation, 22, 23, 122.
Gibb, T. R. P. 24.
Giles, D. J. 170.
Glacier Metal Company, Ltd. 121.
G. N. K. Group Services, Ltd. 21.
Gold, D. 168.
Graham, J. W. 169.
Gresham, H. E. 123.
Gulf Research and Development Company, 121.
Gutzeit, G. 22, 80.

Hadfield, D. 81.
Hanink, H. H. 170.
Harris, G. T. 169, 170.
Harshaw, Chemical Company, 80, 168.
Haupt, K. F. 81.
Heppenstall Company, 169.
Hignett, H. W. G. 21.
Hinton, K. G. 168.
Hitchcock, J. O. 81.

Imperial Chemical Industries of Australia and New Zealand, Ltd. 22.
International Nickel Company, Inc. 21, 122.

Jessop, W. & Sons, Ltd. 81, 169, 170.
Johnson Bronze Company, 121.
Johnson, R. B. 123.
Johnson, W. G. 169.
Jones, L. J. 123.

Kennametal, Inc. 169.
Kirkby, H. W. 24, 82.
Knowlson, R. F. 123
Koren, H. W. 168.
Krief, A. 22.
Krieg, A. 80.

Lancaster, J. F. 82.
Latrobe Steel Company, 170.
Lenz, K. 168.
Lewis, H. 81.
Lewis, J. C. 81.
Lindner, W. J. 124.
Logan, F. G. 80.
Lohr, J. M. 23.
Mabie, Todd & Company, Ltd. 22.
McKinley, J. B. 121.
MacNeill, S. G. 124.
Matheny, D. E. 168.
Metro-Cutanit, Ltd. 23.
Millet, J. 121.
Mond Nickel Company, Ltd. 81, 122, 123, 168, 169.
Mott, N. S. 124.

Nack, H. 22.
National Cash Register Company, 168.
Nelson, B. J. 22.

Odgers, M. 21.
Offenhauer, C. M. 81.

Panseri, C. 122 (corrig. 99).
Pardee, W. A. 121.
Pawlyk, P. 121.
Payne, R. J. M. 122.
Payson, P. 23, 169.
Penrice, T. W. 123.
Poch, S. 81.
Precision Diamond Tool Company, 169.
Pyrene Company, Ltd. 23, 24.

Radio Corporation of America, 21.
Rau, D. W. 80.
Redmond, J. C. 169.
Reschan, R. R. 80.
Rolls-Royce, Ltd. 123.
Rosencrans, S.A. 122.
Round, H. J. 168.

Sandvikens Jernverks, A. B. 82.
Schaufelberger, F. A. 79.
Schempp, R. 23.
Scherer, R. P. Corporation, 82.
Shenk, W. J. 168.
Shute, D. H. 123.
Sintercast, Corporation of America, 170.
Smith, R. A. 123, 169.
Société Accumulateurs Fixes et de Traction, S.A. 121.
Société des Soudures Castolin, S.A. 82, 122.
Société le Carbone Lorraine, 121.
Société Mépaco, 170.
Sonotone Corporation, 168.
Spendelow, H. R. 123.
Spitz, K. 122, 170.
Standard Oil Development Company, 21.
Stokes, C. 24, 82.
Stone, J. & Company, Ltd. 122.
Straumann, R. 22, 122, 170.
Succop, J. A. 169.
Sykes, C. 24, 82.
Sylvania Electric Products, Inc. 168.

Taeyaerts, J. 169.
Talmey, P. 168.
Tanczyn, H. 82.
Teszner, S. 121.
Thompson Products, Inc. 123.
Toulmin, H. A. 22.

Udylite Corporation, 80.
Union Carbide and Carbon Corporation, 22, 81, 123, 124.
Universal-Cyclops Steel Corporation, 23.
U.S. Atomic Energy Commission, 22, 24.
U.S. Secretary of the Navy, 21.

Vacuumschmelze, A. G. 22.
Vickers, Inc. 80.

Wainer, E. 123.
Wasserman, R. D. 82, 122.
Webb, A. W. O. 122.
Webbere, F. J. 23, 122.
Western Electric Company, Inc. 81.
Westinghouse Electric Corporation, 122.
Wheeler, M. A. 123.
Wiggin, Henry & Company, Ltd. 81.
Willson, K. S. 80.

PRINTED IN ENGLAND *by* WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1